KARL GILZIN

TRAVEL TO DISTANT WORLDS

AUTHOR'S NOTE

The youth throughout the world have been manifesting a great interest in the problem of space travel. This interest has long since ceased to be a question of idle curiosity: "Is space travel possible?" Every pupil now knows the answer to this question.

The interest of our young people in the problem of space travel has assumed quite concrete form. They want to know what interplanetary flights are possible today, at the present level of scientific and technical development, they want to know what achievements have been attained in the development of remarkable reaction engines, which will be the vital part of any interplanetary vessel. These young people question the astronomers about the routes of future cosmic flights. They question the doctors about the specific effects of space travel on the human organism. They are interested in the possibility of a collision between a space ship and meteors, in the possibility of using artificial satellites of the Earth and in many other things.

In a few words, our youth are keenly interested in all the problems covered by the science of space travel. This science has already developed to such an extent, especially during the past decade, that it is impossible even to attempt any detailed account of its achievements in any one book.

If this publication succeeds in replying to some of the questions put by our young readers, if it arouses their greater interest and curiosity, its aim will have been achieved.

K. Gilzin

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THE WORLD ABOUT US

INTRODUCTION

Travel to distant worlds.... What worlds does this book talk about?

There was a time when people considered the Earth the centre of the Universe. Only individual scientists, such brilliant minds as Giordano Bruno, were great enough to understand that the Earth is but a speck in the Universe, and that life exists on countless heavenly bodies, inhabited by thinking beings, even though they may, perhaps, be unlike ourselves.

That was not so very long ago, and yet, how far have our conceptions of the Universe advanced since that time! Science is striding ahead, and man is acquiring more and more power over nature. The time will come when people will very likely speak of us with a smile, so strange will our "secluded life" on Earth, this crowded world in which we live, seem to the people of the future. And the day will come when people will not only visit the Earth's "suburbs" in the space about our Sun in their cosmic ships but will even fly to other suns, penetrating further and further into space.

The heavenly bodies in the Universe are infinite in number.

Rotating on their axes and floating around in space at distances so far from us that they defy imagination, are colossal stellar systems, "island universes" or galaxies. Each stellar family consists of many thousands of millions of stars. The distances between them are so great that it takes even a ray of light, travelling at 300,000 kilometres a second, tens and hundreds of thousands of years to travel from one star to another lying at opposite sides of the same stellar family.

Our Sun, an ordinary star located close to the edge of one of these galaxies, also floats about in the cosmos. It is in all respects an average star. There

are giant stars hundreds and even thousands of times larger than our Sun in diameter, and midget stars hundreds of times smaller. Our Sun is colder than countless stars, and hotter than countless others. There are stars more dense than the Sun, others less dense, stars that are brighter and stars that are less bright, and so on.

What is our Sun like, the source of life on Earth?

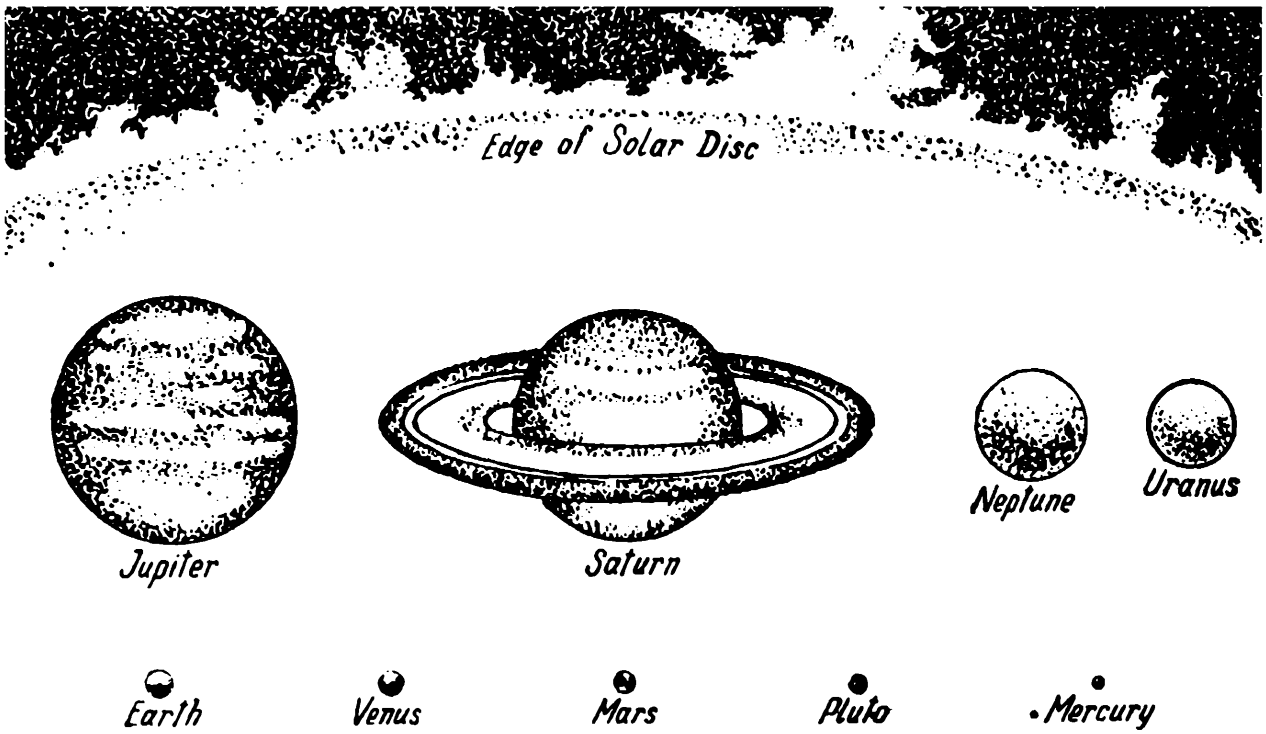
The Sun is a huge, incandescent, gaseous spherical body, the diameter of which is almost 110 times greater than that of the Earth, or approximately 1,390,000 km. Within this tremendous seething gaseous sphere, which slowly rotates on its axis, complex processes are incessantly at work, forming new atoms of helium gas from the simplest hydrogen atoms. Due to these processes, colossal quantities of energy contained in the atomic nuclei are released, with the result that a temperature of about 20 million degrees is maintained in the bowels of the Sun. It is not surprising, therefore, that every second the Sun radiates tremendous energy. The Sun's rays penetrate all the space surrounding it; they bring warmth and light, which are essential for the existence of life. They are life-giving rays. The mysterious processes that go on in the Sun play a very important part in our life: they influence the weather, radio communications, the magnetic phenomena, etc. Hence the importance of scientific study of the "life" of the Sun.

The Sun, like countless other stars, is not alone in its travels in space. It is surrounded by a large family of heavenly bodies which taken together form the solar system. All of these bodies are inseparably bound with the Sun and, judged by cosmic distances, are relatively close to it.

The chief members of the solar family are the planets which revolve around the Sun. They are not hot, but cold, solid, celestial bodies, much smaller than the Sun in size and much more mobile.

One of these planets is the Earth. In other words, "the centre of the Universe" is no more than an ordinary planet, one of the nine planets of the solar system. It is not surprising that the church waged such a fierce war against Copernicus, Galileo, Bruno, against all those who denied the exceptional position of the Earth and man in the Universe, for this latter assertion forms the basis of religion.

What are the planets of the solar system, those closest "relatives" of the Earth?



Relative sizes of planets and the Sun.

The planet closest to the Sun is Mercury, the smallest of them all; then, as we move away from the Sun, come Venus, our Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto, about which very little is known so far.

The distances between the planets are so very great when compared with the dimensions of the planets themselves that the solar system is like a vast desert containing a few grains of sand, the planets, which are lost in its expanses. The following picture may give one an idea of the solar system. If we represent the Sun as a huge ball a metre in diameter, the Earth will be a minute cherry, less than one centimetre in diameter, and at a distance of over 100 m. from that ball. Mercury will be the size of a pea only 3.5 mm. in diameter, situated at a distance of 40 m. from the ball, the Sun, while Venus will be a cherry like the Earth, but at a distance of about 77 metres from the Sun. Mars, the size of a bead about five mm. in diameter, revolves around the ball at a distance of over 160 m. Jupiter, a giant, may be represented as a large orange 10 cm. in diameter and at a distance of over half a kilometre from the ball. Saturn will be an orange with a diameter of about 8.5 cm. and at a distance of about

one km. from the ball. Uranus—a nut with a diameter of 3.5 cm., will be two km. from the ball, Neptune, a slightly larger nut, will be a little over three km. from the ball, and, finally, Pluto, also a pea slightly over 44 mm. in diameter, more than four km. from the ball, the Sun.

Our knowledge of the planets is by no means insignificant, but what, indeed, does it amount to compared with what we still have to learn!

We know, for instance, that Mercury is almost completely devoid of atmosphere and that one and the same side of this planet always faces the Sun. What we also know about Mercury, as well as about all the other planets (except Pluto), is how big it is, what its mass is, and what laws govern its motion.

Venus has a dense atmosphere, but one that does not resemble that of the Earth in composition, and, unfortunately, it is so difficult for the visible solar rays to penetrate it, that as yet we know very little about the appearance of the surface of our neighbour.

Another such neighbour is the enigmatic Mars, about which, however, we have learned more than about the other planets. Mars has an atmosphere similar to that of the Earth, but more rarefied. It also has water. These are firmly established scientific facts. In recent years Soviet scientists have obtained experimental proof of the fact that there is also vegetation on Mars.

Jupiter is renowned for its dimensions—it is a giant as compared to the other planets: its diameter is more than 11 times that of the Earth. A dense, impenetrable layer of clouds envelops this planet.

Saturn is beautiful with its famous necklace of rings. Like the next two planets, Uranus and Neptune, opaque clouds envelop it.

We finally come to the outermost planet of the solar system, Pluto. It very likely has a frozen atmosphere that covers its surface with a solid layer, for the temperature on Pluto, from which the Sun appears to be just a blindingly bright star, probably reaches —220°C.

Some of the planets, namely Mercury, Venus and, possibly, Pluto, make their endless flight around the Sun in complete solitude, whereas the others have satellites, smaller in size and which in turn revolve around the planets in their own orbits. This family of planetary satellites has as many as 30 members, not counting the Earth's well-known satellite, the Moon.

One Sun, nine planets, and 31 satellites.... Is that all?

No, that is far from all.

Besides these "inhabitants" of the solar system, we should mention the tens of thousands of minute planets, the asteroids. They also revolve around the Sun, but in the most diverse orbits, sometimes coming so close that they almost touch the Sun, and sometimes moving at tremendous distances from it.

Then there is a very large group of heavenly bodies whose origin is a riddle: the comets—"shaggy stars," usually adorned with long, beautiful tails. These comets also revolve about the Sun, but they usually move along such elongated elliptical orbits that a year on one of these comets might last tens of thousands of terrestrial years. No wonder that the comets are sometimes called the vagabonds of the Universe.

Finally, there is a countless armada of heavenly stones, meteors, which are fragments of large extinct heavenly bodies. These stones penetrate the solar system from all directions.

Well, that seems to be about all.

And yet, should we become acquainted with the solar system at some time in the future, we may be able to see artificial heavenly bodies created by man—interplanetary vessels and artificial satellites of the Earth.

Indeed, the time is not far away when we will witness the realization of this greatest of man's dreams.

This book tells you how man is preparing to take a leap into space, about the extraordinary difficulties he will have to overcome and the wonderful opportunities space travel promises.

Part One

FROM FANTASY TO SCIENCE

The impossible of today will
become the possible of tomorrow.

K. E. TSIOLKOVSKY

Chapter 1

A BOLD DREAM

We are living in a remarkable period. The features of the communist society which the Soviet people are building stand out more clearly with every passing day. There are times when the wildest imagination, the boldest dreams of man are surpassed by reality.

In their striving to promote the cause of peace, Soviet people endeavour to make the fullest possible use of their natural resources. They have been setting remarkable examples of heroic labour and accomplishing wonders.

The Lenin Volga-Don Canal, the age-old dream of the Russian people has been built. Construction of the Kuibyshev and the Stalingrad power stations, which are among the largest in the world, and many other power stations, canals, irrigation systems and dams, is proceeding at a rapid pace. More and more often we find the names of mighty Siberian rivers mentioned in our newspapers. Their inexhaustible water supply, together with the waters of the Volga, the Dnieper and the Don, will be made to serve the Soviet people by producing cheap electric power. Deserts succumb to the efforts of Soviet people, equipped with the most modern science and technique; age-old virgin soil is upturned; rivers change their courses, and the face of the Earth is changing incredibly. New giant plants begin to operate, beautiful cities arise, and fields and gardens blossom forth. The life of the Soviet people is becoming better and more beautiful.

Electricity and chemistry, atomic energy and marvellous automatons, Michurin's biology and the radio, hundreds and thousands of wonderful discoveries by Soviet scientists, inventions of engineers and workers—everything is being put to use by the Soviet people in their magnificent fight to transform nature.

Can we doubt that the bold dream of mankind as regards space travel will be realized?

The dream of flying originated with our distant ancestors.

When primitive man tried to make his way through the heavy growths of liana in the impassable jungles, he could not help envying the birds which so easily soared in the sky above him. It is quite natural that this dream found reflection in numerous folk legends.

One legend, which originated over 3,500 years ago, inspired the great Tajik poet, Firdousi, to make a poem of it. It tells how the Persian sovereign, Kaikaus, attempted to fly to the sky. Having conquered all the world, as he knew it, he decided to subdue the sky and subjugate the "realm of the clouds." He ordered a chariot to be built of the lightest wood, and four young, strong eagles, caught especially for this purpose, to be harnessed to it. After getting into this "airplane" of his, with all the necessary equipment and arms, the monarch gave the command and the eagles were released. In their attempt to obtain the piece of meat fastened in front of each of them, the eagles took off, carrying with them into the sky the chariot and its "pilot." However, these living "engines" grew, tired of this meaningless game, and the luckless conqueror, disappointed returned to the Earth.

And who doesn't know the ancient Greek legend of the carefree Icarus, son of Daedalus, who rose into the air on wings made of feathers which were stuck together with wax, but who imprudently drew too near the Sun and perished? The fate of Icarus may befall future space travellers to Mercury if the pilot of their vessel makes the slightest mistake in navigating.

For many thousands of years flying remained but a dream. Man, nature's sovereign, was not meant to fly. People learned to sail, they built boats and conquered the water expanses of the Earth, but the world at their disposal still remained flat—the sky was still inaccessible to them. People walked along the bottom of the greatest of all oceans—the atmospheric—and could merely dream of floating off into that ocean, of flying upwards.

Brave, courageous Russian people also endeavoured to rise to the skies. This cherished dream of flying is widely reflected in the tales and legends of the Russian people. We need but recall the flights made by Ivan-Tsarevich, or the tale of the Hunchbacked Horse. It was in Russia that this cherished dream of flying was at last realized. The first plane to carry man to the skies was built by Alexander Mozhaisky, the founder of modern airplane designing. That marked the beginning of a new era, the era of aviation.

Closely bound up with the dream of flying in general was the dream of flying to the stars. People knew nothing about the structure of the Universe, nor what the stars were like, but their creative imagination carried them to those distant lights. The mythology of all ages and of all peoples abounds in legends about flights to the stars. These legends sing the courage of brave men, of their creative daring.

As the science of the structure of the Universe and our solar system developed, dreams of flying to the stars began to acquire new meaning. And when we dream of interplanetary flight, we speak of it, first of all, as of a great scientific achievement.

Indeed, interplanetary flight would be of exceptional scientific significance.

During flight and when on the surface of the Moon or the planets, it would be possible to make diverse scientific observations such as cannot be made on Earth. There is no doubt whatever, that as a result of such a flight many secrets of nature would be revealed, science would make tremendous strides forward, and a new era would begin for a number of branches of sciences. All fields of the natural sciences such as astronomy, physics, chemistry, geology and biology would be immeasurably enriched with new data, and new sciences as yet unknown to us would come into being.

What a mysterious, thrilling, extraordinary world would open up before those terrestrial beings who first reached the Moon, Mars, Venus! New forms of plant and animal life, unknown to us on Earth, might be discovered on the planets. The time may come when our terrestrial travellers will even reach such planets, where thinking beings exist, though they may be unlike you and me.

But it is not only the possibility of wonderful scientific discoveries that makes the idea of cosmic, interplanetary travel so attractive. We

study nature not merely for the sake of studying it, but in order to make it serve mankind better. And in this respect, space travel would open up new, truly colossal opportunities.

The planets may prove to be inexhaustible storerooms of many useful minerals. Science has established the fact that all these worlds of the Universe known to it consist of one and the same chemical elements, which are covered by the periodic law of the elements, discovered by Mendeleyev. However, the planets may contain ores and minerals rarely to be found on Earth and which may even be entirely unknown to us. For it is a fact that such minerals are found in the celestial stones or meteorites that fall to the Earth.

Everyone knows that the basic source of life on Earth is the generous supply of energy from the Sun. However, the Earth is but a speck in the space around the Sun, and that speck receives less than one two-billionths of all the energy radiated by the Sun. Yet one must not think that this solar energy received by the Earth is little. Judged by its absolute magnitude it is a tremendous amount. But man makes very little use of this energy. The time will come, however, when this situation will change.

Not only will the wind, water, coal, oil and other forms of energy, into which the energy of the Sun is transformed, be used, but it will be used directly. Even then, when we take into consideration the increasing needs of man, it may prove insufficient for the realization of his gigantic projects. When that time comes, part of the Sun's energy which is now going to waste in space may, along with the energy of the atomic nucleus, come to the aid of man.

It will be most convenient to set up solar power stations of tremendous capacity on the Moon and on Mercury, as they have no atmospheres and are not far from the Sun. The power produced by these stations will best be used right there, in particular to supply the chemical plants operating on "local" raw material and poducing fuel for the rocket engines of interplanetary vessels. Then, perhaps, methods will be found to transmit this energy to the Earth. It is even possible that such solar power stations will be set up not on the planets themselves, but right in interplanetary, cosmic space.

We can go even further and say that a time will come when communities of people will appear on the Moon, Venus, Mars and, perhaps, on other planets and their satellites. Needless to say, at the present time

these planets are not adapted for the life of people who are accustomed to terrestrial conditions. But by making use of the colossal quantities of energy which will become available in the future, man will be able to interfere in the "life" of the solar system and change the order of things that has existed there for thousands of millions of years. Scientific knowledge, for instance, makes it possible, in principle—we shall speak of this in greater detail later—to change the relative positions of the planets, for example to move Mercury, which is now dangerously close to the Sun, farther away, so as to make the temperature conditions on Mercury more similar to those on Earth, or, for the very same reason, to move Mars closer to the Sun. These are but a few of the opportunities which the realization of interplanetary flight will make possible.

Today it is difficult even to conceive of all the prospects awaiting mankind when people will be able to visit the most out-of-the-way places of the solar system, and the solar system will have, at last, acquired a real, wise, forceful master.

Chapter 2

PRISONERS OF THE EARTH

What prevents us from travelling into space? Where lie the chief difficulties? After all, how does such travel differ from travel on Earth? Perhaps only in the fact that such travel covers greater distances?

Or in the fact that it will take place in airless space, where vicious cold dominates?

Or, finally, simply because such a journey has never as yet been undertaken and may be fraught with all sorts of unexpectednesses?

Yes, for these and for many other reasons. There is one circumstance which makes any sort of interplanetary journey, even the shortest, different in principle from any journey on Earth, even a round-the-world voyage; it is the chief difficulty that prevents us from making such a journey.

You can guess, of course, what we have in mind: the force of gravity.

The force of gravity (or the force of gravitation, as it is sometimes called) is the force of the mutual attraction of material particles, one of the most important forces in nature. Science has not as yet succeeded in fully explaining the origin or the nature of this force. But the character

of this phenomenon and the magnitude of the force of gravity have been studied at length.

The force of gravity manifests itself everywhere, wherever there are at least two bodies or two material particles; it influences such particles all over the Universe. That is an absolutely universal law. That is why the law of gravitation, discovered by Newton, is called the law of universal gravitation. Any two bodies, any two particles are drawn towards each other with a force that depends on the masses of these particles and the distance between them. The larger the mass and the less the distance, the greater will be the attraction.

We come upon the phenomena of the force of gravity all the time. Our weight is the force with which the Earth attracts us. All objects on Earth have weight. An apple torn off a tree does not head for the sky, but falls to the Earth under the influence of the force of gravity.

Incidentally, this last explanation is not indisputable. If, besides the apple and the Earth, there were no other bodies in the Universe, there would be but one path for the apple to take—towards the Earth. However, as a matter of fact, the apple is attracted not only by the Earth, but also by the Sun, the Moon and other heavenly bodies. If, despite this, it falls only to the Earth, that is merely because its attraction towards the Earth is immeasurably greater than towards any other heavenly body, for the Earth is much closer. For just the same reason, in many other cases we may consider only the two bodies that attract each other, as the Earth and the apple, disregarding the influence of the others.

Incidentally, it became possible to formulate the theory of the movement of heavenly bodies in the solar system only as the solution of a "problem of two bodies." As regards the "problem of three bodies," to say nothing of a greater number, it has not been possible as yet to find any general solution because of mathematical difficulties. It is, therefore, necessary to consider the influence of other bodies as distortions, or so-called perturbations, which these bodies cause in the trajectories of motion, calculated for two bodies.

One must not, however, get the idea that we, here on Earth, ignore the attraction of the Sun or the Moon simply because it is slight in its absolute magnitude. It is a known fact, that such natural phenomena as high and low tides, when thousands of millions of tons of oceanic water are brought

into motion, are due to this attraction. Some day in the future the energy produced by this water will be used to operate most powerful "tidal" hydropower stations. Even Neptune, one of the outermost planets of the solar system, which is at a distance of over 4,000 million kilometres from the Earth, exerts a force of 18 million tons upon it.

The force of gravity plays a tremendous and, needless to say, positive role in nature. If there were no force of gravity, the Universe would not have such a highly organized appearance as it now has. There would, of course, be no solar system, nor would man be in existence. And even if we did exist, we would not be able to stick to the surface of the Earth—one light push would be sufficient to send us wandering in the vast expanses of the Universe, after taking leave of our native places forever.

However, the force of gravity plays quite a different role when we consider the possibility of space travel. Indeed, when we travel on the surface of the Earth, we do not notice the effect of the force of gravity except, perhaps, in high mountain climbing. But an interplanetary flight is quite a different matter. When making such a flight we must get farther and farther away from the Earth all the time, which means we must overcome the force of gravity. The force of attraction towards the Earth, which protects us from the danger of accidentally flying off it, does not permit us to part from it even if we wish to. And so this "alliance" with the Earth may be compared to a form of captivity.

How can we sever those powerful chains of gravitation which transform us into "prisoners" of the Earth? How can we overcome this chief obstacle that stands in the way of space travel?

Those well-known means by which people, from times of old, stormed the sky, overcoming the force of gravity—the balloon and the airship—are of no use in interplanetary flights. In order to fly they need air, and air is not to be found in space.

However, science has found a means. It is speed, the speed that must be imparted to the interplanetary vessel.

If we want to impart a certain speed to any object, as, for instance, to an ordinary stone, we must throw it. The greater the force with which we hurl it, the greater its speed. The strength of a person's muscles is not great, of course—a world champion can jump over a bar set at a height slightly over two metres. A stone cast by the strongest arm will

rise from 20 to 30 metres. But here is where the intellect comes to the aid of muscle. An arrow released from a taut bow will fly for tens and even hundreds of metres; a bullet shot from a rifle will travel several kilometres; and a shell fired from a long-range gun will rise in the air to a height of 40 kilometres.

Ever higher and farther.... Isn't it possible to take such a swing with a stone as to hurl it to ... the Moon? In principle it is, but it would have to be thrown with tremendous force.

The greater the force with which we hurl the stone, the greater its initial speed, and the greater this speed, the higher the stone will fly. A stone hurled upwards with a definite initial speed, gradually flies slower and slower until it stops completely for an instant, and then it begins to fall back to the Earth faster and faster. What slows down the flight of the stone when it moves upwards, and what increases its speed when falling? The force of gravity. If the air in which the stone makes its flight did not offer it any resistance, thus lessening its speed, the stone would, on striking the Earth, possess the very same speed which was imparted to it when hurled.

This enables us to determine the speed which must be imparted to the stone if it is to reach, let us say, the orbits of the Moon or Mars. A stone hurled at such a speed will reach the orbit set it, and then it will begin to fall back to the Earth faster and faster.

Is it possible to impart such a speed to the stone, that it will not return to the Earth at all, but will continue to move endlessly, farther and farther away from it, into space? It is possible, at least in theory. This speed must be equal to the speed the stone would have when falling to the Earth "from infinity," as the mathematicians word it.* Here, by "infinity" we simply mean "very, very far," so far that even a considerable increase in the distance no longer changes the speed with which the stone falls back to the Earth. For instance, if one stone falls to the Earth from a height of 10 million km., and another from a height of 20 million km., the difference in the speeds of these two stones will be absolutely insignificant.

* As above, we are ignoring the resistance of the air, that is, we consider the stone as falling in a void; moreover, we are considering the problem of two bodies, that is, we assume that besides the Earth and the stone there are no other bodies in nature. We also are not taking into consideration the rotation of the Earth on its axis.

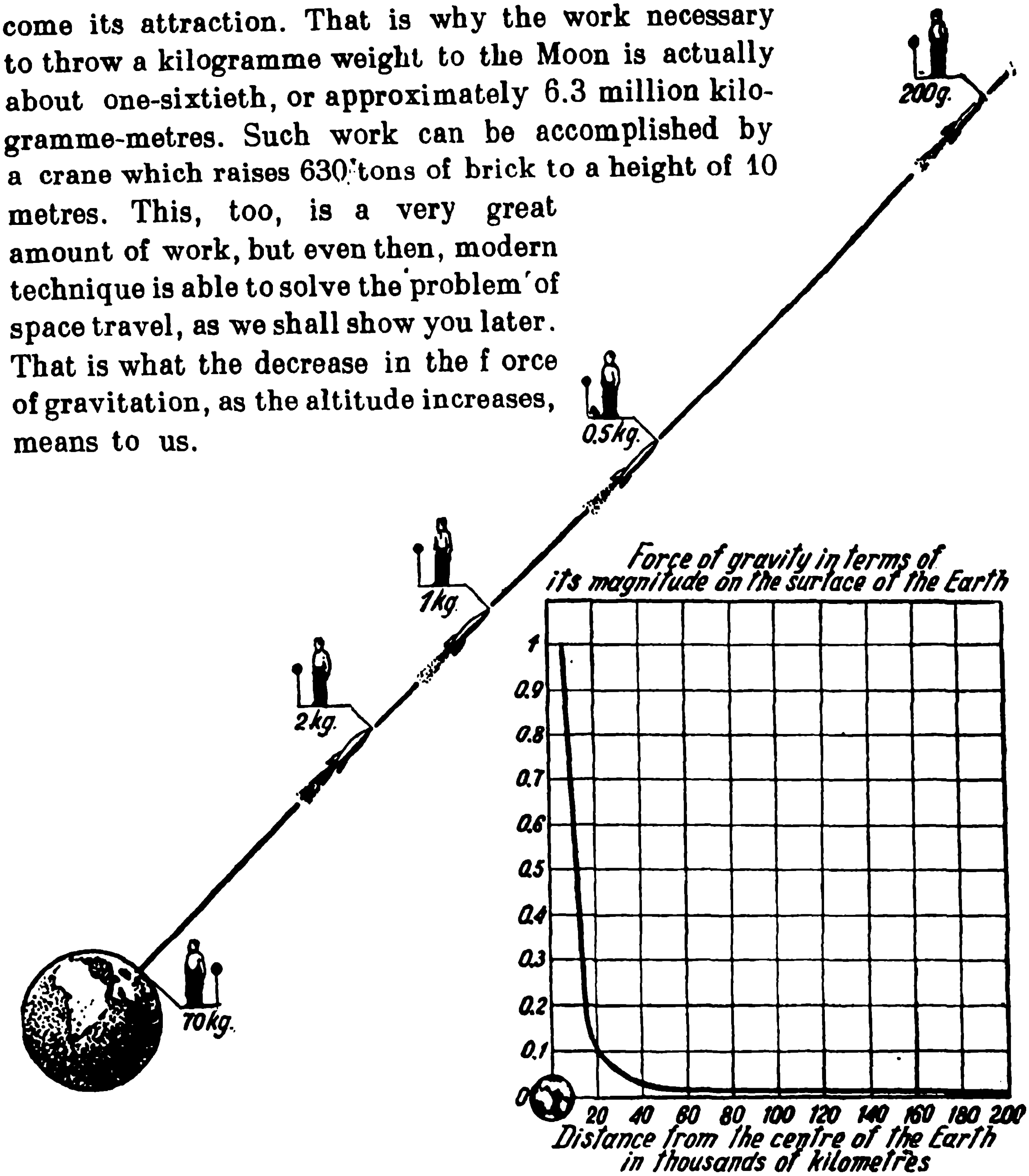
The speed that must be imparted to a stone (or any other body) in order to make it fly off the Earth, never to return to it, but to continue its flight away from the Earth, is usually called the escape velocity.

When we impart such speed to a stone, it does not mean, as some are inclined to think, that the stone flies so far from the Earth that the force of attraction ceases to influence it and the stone no longer is attracted by the Earth. There is no such point in space where the force of gravity ceases to function, including the force of attraction to the Earth. The force of attraction to the Earth functions everywhere, only its magnitude may become insignificantly small if the stone is far from it. This magnitude is inversely proportional to the square of the distance from the centre of the Earth: when the distance increases twofold, the force of attraction is one-fourth; when it increases threefold, the force of attraction is one-ninth, etc.

In other words, it is just this singularity of the law of universal gravitation that makes interplanetary flight possible. If the force of attraction to the Earth remained constant irrespective of the altitude and did not decrease so rapidly, we could not even hope to travel in space, unless, perhaps, in the very distant future.

We can easily prove the truth of this statement. In order to sever the chains of the Earth's attraction, a certain amount of effort is necessary. How can we determine the magnitude of this effort? When we lift a load of any kind, let us say one kilogramme to a height of one metre, we perform work which, as we know, is equal to one kilogramme-metre. If we decided to raise this load to a height of 384 million metres, that is, if we decided to throw it to the Moon, we would, if the force of gravity were constant, have to perform 384 million times as much work. That is the work an engine with a capacity of about 1,500 horse-power performs in one hour. But the very lightest space ship must weigh tens, if not hundreds, of tons. And so the required power of the ship's engine and the fuel expenditure for such a flight would be so enormous that the solution of this task would be beyond the means of modern technique. Fortunately, this would be the case only if the force of gravity were constant and did not change as the altitude changed. In reality, however, as we pointed out above, the force of gravity decreases as the object withdraws from the Earth. The further away from the Earth, the easier it is to over-

come its attraction. That is why the work necessary to throw a kilogramme weight to the Moon is actually about one-sixtieth, or approximately 6.3 million kilogramme-metres. Such work can be accomplished by a crane which raises 630 tons of brick to a height of 10 metres. This, too, is a very great amount of work, but even then, modern technique is able to solve the problem of space travel, as we shall show you later. That is what the decrease in the force of gravitation, as the altitude increases, means to us.



The force of gravity is inversely proportional to the square of the distance from the centre of the Earth.

The escape speed of a stone is the speed necessary to ensure that it wil continue to fly away from the Earth without ever returning. If the speed of the stone is less than is necessary, the stone will, sooner or later, inevi-

tably fall back to the Earth.* At a speed greater than the escape speed the stone will not, of course, return to the Earth, but this surplus speed would simply be wasted.

What is the escape speed equal to?

Only with the aid of higher mathematics can we determine the magnitude of this speed. Its magnitude is determined by the fact that the kinetic energy which the stone acquires when it is imparted such a speed, must be equal to the work of overcoming the Earth's attraction, as shown above. That will be approximately 11.2 km. a second, or 40,000 km. an hour. This is the speed that must be imparted to an interplanetary vessel if it is to break through that invisible "armour of gravitation," as Tsiolkovsky so aptly put it, and fly to the Moon or other planets of the solar system.

Chapter 3

THE BIRTH OF SCIENCE

When man first came to understand the connection between velocity and gravity, he took his first step from fantasy to science. However, this did not mean that the science of space travel had come into being. One more problem had to be solved before it could be created, namely, how to attain the desired velocity.

Generally speaking, this problem can be solved in various ways. For instance, in theory it is possible to make a giant bow or build an equally giant catapult to send off an interplanetary missile by means of elastic force. One can also use a sling or projectile machine similar to those used during the Middle Ages in the besieging of fortresses. However, theory is one thing, the technical realization—another. Needless to say, in actual practice neither of these means is satisfactory as such units cannot be made sufficiently durable.

Isn't it possible to use a gun to fire an interplanetary missile? This question naturally arises, for it is a commonly known fact that a missile ejected from a long-range artillery gun has a velocity of 1.5-2.0 km. per second. That, of course, is still less than the required 11 km.; but the

* Here we refer to the vertical flight of a stone. Other cases will be considered n Chapter 15.

magnitudes attained are sufficiently close to what we need to arouse our interest in the gun as a means of effecting space travel.

Everyone probably remembers it was this very idea that Jules Verne used as the basis for his scientific romance *From the Earth to the Moon*. Jules Verne describes a gigantic gun cast right in the Earth, in the form of a deep vertical well over 270 metres in depth. According to his calculations, a projectile fired from this gun could not fail to reach the Moon. Jules Verne placed his travellers inside this projectile.

However, it would not be possible to make a trip through space as Jules Verne suggested. The important thing here is not the fact that Jules Verne erred seriously in his calculations, and a projectile fired from his gun would not only not reach the Moon, but would not even get beyond the limits of the Earth's atmosphere: the projectile would simply make a relatively small arc in it and then fall back to the Earth. That, of course, is something that could be corrected, and even if such a gun could not be built, the calculations for such a gun could be made, so that its projectile would reach the Moon, although this would be impossible with the gun powder now employed by modern artillery. We might even forgive Jules Verne his error in principle, namely, that his trip would be a one-way affair, no return being possible, for there would be no gun on the Moon to send the projectile back to the Earth!

The chief obstacle preventing us from sending man to the Moon in a projectile is based on something quite different. It is here that we first come up against something which, together with velocity, plays an exceptionally important role in the problem of space travel. This "something" is the acceleration that arises during such a flight.

The magnitude of acceleration shows how quickly the velocity of the flight changes, that is, how quickly it increases at the take-off and decreases when the brakes are put on. We can impart the necessary escape velocity to a space ship gradually, over a long period of time; in this case the take-off will be smooth and the acceleration small. But it is also possible to impart to the ship the necessary velocity in a short space of time and sharply; in this case the acceleration will be great. The same applies to the landing of the ship: its braking can be sudden or smooth, as a result of which the acceleration will be correspondingly great or small.

It is readily understandable that this is a matter of no slight importance for the ship's passengers and for the ship itself. Everyone knows from

his own experience how unpleasant great acceleration is. One needs only to recall one's feelings when a tram or automobile in which one may be riding suddenly starts or stops, or makes a sharp curve. Air pilots, in particular, are familiar with these sensations, when executing intricate figures in the air: the Nesterov loop, the roll, or when veering. Some powerful force either presses them down to their seats or, on the contrary, whirls them out of their seats. Where does this force come from?

So long as the velocity is constant, no matter how great it is, we do not feel it at all, and cannot even suspect that we are moving. Does anyone ever stop to think that, together with the Earth, he is constantly whirling around the Sun in space at a rate of 30 km. per second? Of course not! But if the velocity of the Earth's motion were suddenly to change sharply, becoming either greater or less, the situation would be quite different. Incidentally, it would be better not to enumerate all the unpleasantnesses that the inhabitants of the Earth would experience if they ever came to feel this powerful force.

This force, which always appears when acceleration occurs, is called the force of inertia.

When a lift begins to rise, acquiring acceleration, the passengers in it feel as though some load were pressing them to the floor, as if their weight were being increased. It is the floor of the lift that presses against the passengers, overcoming their inertia and their attempt to preserve their state of rest. The greater the acceleration of the lift and the quicker it increases its speed, the greater will be the force of inertia and this increased weight of the passengers. The force of inertia is directly proportional to the acceleration. When the lift stands still, only the force of attraction presses the passengers to the floor of the lift, that is, their own weight. When a body falls in a void this force causes an acceleration equal approximately to 10 metres per second for every second of the fall, more exactly—9.81 metres. This is the so-called acceleration of a free fall or the acceleration caused by the Earth's gravity. If the lift begins to rise at such an acceleration, that is, if its velocity is increased every second by 10 metres per second, the passengers will be pressed to the floor of the lift not only by their own weight, but also by a similar force of inertia, and the weight of the passengers will seem to be doubled. It goes without saying that such an "increase" in weight is by no means pleasant.

The passengers enclosed in that unique lift of Jules Verne's, his projectile, will feel the effects of tremendous forces of inertia, for the velocity of the projectile must increase during its motion in the gun barrel from 0 at the beginning of its motion until it attains a velocity of 16 km. per second* at the end of its trip. The acceleration of the motion will be tremendous. According to calculations, it will be about 60,000 times the acceleration of the Earth's attraction. But this means that the weight of the passengers in the projectile will be just so many times their usual weight—a passenger will weigh up to 3,000-4,000 tons! This tremendously increased weight would crush these wretched travellers, and nothing would remain of them but a spot on the bottom of the projectile. As far as the fate of the passengers is concerned, it would make no difference where they were at the time the projectile was fired—inside it or right in front of it.

The inertia overloads resulting from accelerations in flight are just as harmful to the ship itself as they are to the ship's passengers. There have been cases when a plane, coming out of a dive, ended tragically. If a pilot, after making a precipitous descent, turns his plane upwards too suddenly, the wings of the plane cannot hold out and break under the overload caused by the force of inertia. The time has long passed when people said of a plane that "it is not a machine and cannot be calculated." The science of calculating the reliability of planes has been developed to a high degree of perfection. Naturally, this calculation is made for very definite inertia overloads, and space ships will be calculated in this way.

So we see, it is not sufficient to impart a tremendous velocity to an interplanetary ship; this velocity must be imparted gradually, evenly, without great acceleration. We will tell you later just how great these accelerations may be. The only thing now clear to us is that Jules Verne's cannon does not meet this demand. Incidentally, any other cannon will suffer from the same defect.

It is inexpedient to use guns or any form of catapult to send space ships off not only because of the unallowable accelerations which develop

* This value for the velocity is given in the romance *From the Earth to the Moon* (16,576 m. per sec.); it is greater than the escape velocity because of the need to overcome the air resistance of a flying projectile, which decreases its velocity.

in such cases. Even if it were possible in some way or other to overcome this main difficulty, which is very unlikely, there are other defects inherent in this method. One of these is quite obvious—the projectile will fly along a previously set path, and the possibilities of guiding its flight are very limited. This fact will hardly be to the liking of the pilot. Even Jules Verne's projectile did not reach its destination. This, by the way, proved to be a saving feature, for how would his readers have found out about the adventures of his heroes?

There is a more important problem: the landing of such a ship on a planet. We can hardly conceive of such a landing as the collision between a projectile and its target.

Finally there is another defect in such a ship, one which, although less obvious, is also very important, that connected with the specific features of the atmosphere that surrounds our Earth. We shall consider these specific features in greater detail later on, for besides the "armour of attraction," as Tsiolkovsky worded it, the space ship will have to break through the "armour of the atmosphere," which separates us from space. There is, however, one specific feature which is very obvious—as the altitude above the Earth becomes greater, the density of the atmosphere rapidly becomes less.

The densest strata of the atmosphere lie right on the surface of the Earth. It is through this densest atmosphere that the ship will fly during the first tens of kilometres of its distant trip. And here, at the very beginning of its trip, the ship should fly at a low speed, as this will considerably decrease the loss in the ship's velocity occasioned by the resistance of the air; in other words, it will decrease the loss of energy spent in overcoming the resistance of the atmosphere. Furthermore, it will eliminate the danger of overheating the surface of the ship, which is inevitable when flying at a great velocity in a dense atmosphere. We shall speak of the resistance of the air and the overheating of the ship in greater detail later on, but what is obvious at once is that it is desirable to organize the flight of a space ship in such a way, that its velocity will become cosmic only at a respectable distance from the Earth, in a rarefied atmosphere.

Thus we see it is not such a simple matter to organize the flight of a space ship: the required velocity for such a flight must be many times greater than the maximum velocity ever achieved by man; during the

launching of the ship the accelerations in the velocity must be very slight, the take-off must be smooth; at low altitudes, in dense air, the velocity must be relatively low; the ship must be able to guide its flight, and measures must be taken to ensure a smooth landing at the destination.

The first person to find the means of solving all these problems, which at first glance seem unsolvable, he who can rightly be considered the founder of the science of interplanetary communication or astronautics is Konstantin Eduardovich Tsiolkovsky, whose name will always remain in the hearts of the people as an example of bold scientific thought, an example of creative daring. The Soviet people also revere the memory of scientists of other lands, such pioneers of astronautics as the Frenchman Esnault Pelteric, the American Goddard, the Germans Oberth and Valier and many others.

Back at the end of the 19th century Tsiolkovsky, a modest provincial schoolteacher, became interested in the problem of space travel and succeeded in solving many problems connected with the theory of it.

A scholar, investigator and innovator in science, Tsiolkovsky also proved to be a bold innovator in technique, a remarkable inventor and engineer. He created a wonderful engine without which space travel would be inconceivable; he drew up plans for a number of projects of interplanetary ships and found the answers to numerous practical questions connected with the problem of space travel.

There wasn't a single important problem concerning cosmic flight, which Tsiolkovsky wasn't aware of. There wasn't a single problem concerning interplanetary communication, for which Tsiolkovsky didn't have a bold, original solution.

In tsarist Russia Tsiolkovsky's remarkable works could not find support in the bureaucratic, conservative government. In spite of the great importance attached to his work even then by such universally famous scientists as D. Mendeleyev, A. Stoletov, M. Rykachov, N. Zhukovsky and others, during the more than 40 years of his pre-revolutionary work as a scientist and inventor, Tsiolkovsky only on one solitary occasion received financial aid from the Russian Academy of Sciences, and then it consisted of the magnificent sum of ... 470 rubles!

Living on the insignificantly small salary of a schoolteacher in the town of Borovsk, later in Kaluga, almost deaf as a result of some childhood

illness, Tsiolkovsky spent all his free funds on experiments in which he was interested. He built models, apparatus, instruments and also the first aerodynamic tube in the world. The uninitiated regarded him a "freak," an idle dreamer.

Only after the people took the reins of government into their own hands did Tsiolkovsky have an opportunity to develop his ability to the utmost. During the years of Soviet rule he wrote and published over four times as many books as before the Revolution—550 out of a total of 675. Tsiolkovsky became the ideological inspiration and head of a whole school of talented Soviet scientists, investigators and engineers, who developed the ideas of their teacher.

Part Two

A MIRACULOUS ENGINE

Chapter 4

THE THIRD BIRTH

Tsiolkovsky found an astonishingly simple solution to the seemingly unsolvable problem of how to organize the flight of a cosmic ship so as to meet the chief requirements, those discussed in the preceding chapter.

It was clear that simply thrusting an interplanetary ship into space would not do; it had to be thrust there in a special way. Its force would have to be tremendous if the ship was to acquire a colossal velocity. The process of thrusting it would have to be long-drawn out, so that the launching of the ship would be smooth and long enough for it to fly through the dense strata of the atmosphere at a low velocity. But even this is not enough. The commander of the ship must be able to change its direction and velocity in space as he sees fit, otherwise the ship will simply become the plaything of the elements and will not answer its purpose.

But this means that the push imparted to the ship at the take-off must not be the only one. Other similar pushes may become necessary, and it may even be known beforehand that they will be necessary during the flight itself, when the ship's commander must be able to select the moment for making such pushes, must be able to determine their intensity, duration and even direction. They will have to be special, directed pushes.

What is most important is that such additional pushes become necessary when the ship is whirling along in space, where there is no air against which it can push off, where there are no blowing winds, nothing solid underfoot, as when taking off from the Earth. Obviously, the only solution would be in finding the source of those pushes in the space ship itself.

Such a solution is possible, and it was this solution, the only possible one, that Tsiolkovsky found.

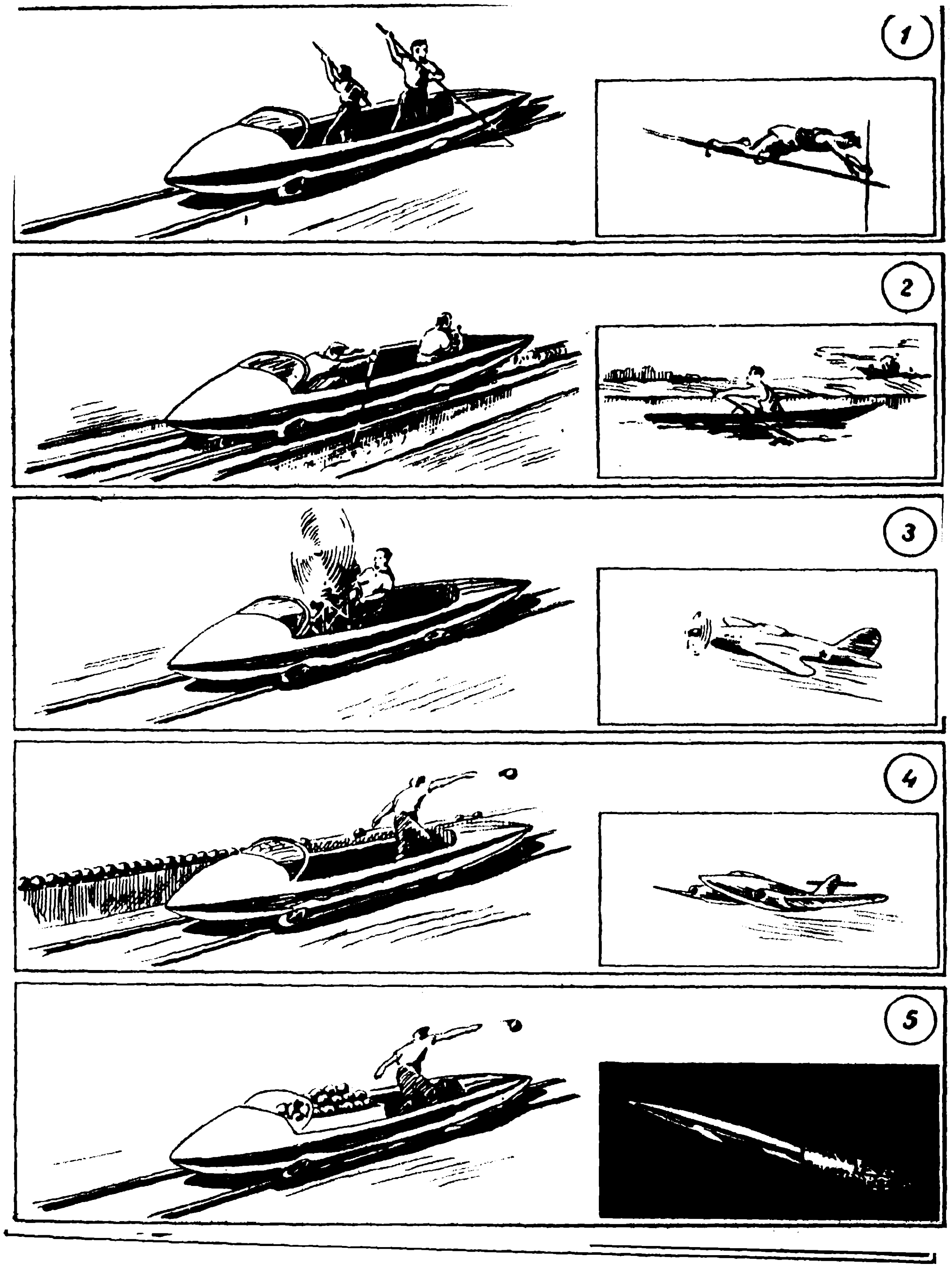
Tsiolkovsky proposed using the reaction principle for interplanetary flights. He suggested installing in the space ship a reaction engine which he had invented. This remarkable idea of his forms the basis of all modern astronautics.

Every school child knows what the reaction principle is. Incidentally, people knew about it and used it from times of old, although it was formulated as a scientific principle only in the 17th century by Newton.

Let us take a look at these pictures. They represent a race in some strange-looking boats. These boats are set on wheels capable of moving along a horizontal track. In order to start off on their journey the boats must be given a push forward. The racers try to reach their destination by various means.

For instance, the passengers in boat No. 1 have decided to push off from land by means of boat-hooks, the way rowers do when stuck in shallow water. When pushing against the Earth, the passengers apply a certain force. But every action has an equal and opposite reaction—that is one of the basic laws of the science of motion and mechanics. The Earth pushes against the passengers and the boat they are in with an equal force that is applied in the opposite direction, or with an equal force of "reaction." A push of one and the same force moves the body forward at different velocities, depending on the mass of the body. The velocity of the Earth's motion, when it is pushed by the passengers, is insignificant since the Earth's mass is tremendous. But the boat, which is light, acquires noticeable velocity, just as an athlete does when he pushes off from the ground in order to jump over a bar.

The racers can push off against something else, other than the Earth. Taking advantage of the fact that running parallel to the tracks of boat No. 2 there are long channels filled with water, the passengers of this vessel push off against the water with oars the way rowers do in a rowboat, and using a screw-propeller as a motor-boat does. The force of the push of the oars and the screw-propeller in this case makes a certain mass of water, affected by them, move backwards with a certain velocity. The greater the push, the greater the accelerated mass of water and the velocity of its motion. The equal and opposite force of reaction of the repulsed mass of water makes the boat move forward.



Motion under the influence of the forces of reaction.

Boat No. 3 has no water to push off against, but its passenger just as effectively pushes off against the air around him. For this purpose he has to use a propeller, which makes a large number of turns when rotating, as it would on an ordinary airplane. This propeller throws the air back, forcing it to move at a greater velocity; the force of reaction of the repulsed air shoves the boat forward. Again the force of reaction!

However, if we so desire, we can get along without boat-hooks, without oars and propellers, without all this "motor" power, by means of which the passengers in boats 1, 2 and 3, labouring by the sweat of their brow, create the push necessary to move their boats. Let us see what the racer in boat No.4 has thought of! He has erected a long trough beside the railway and has filled it with iron balls. The racer has taken a ball from the trough and throws it behind him. The force of reaction of this ball pushes the man who hurled it, and his boat moves forward together with him. So long as the boat moves the length of the trough and there are balls in the groove, the velocity of the boat's motion can keep increasing as a result of the reaction of the hurled balls. Such motion which results from the hurling of a mass and which takes place without the aid of any motors is usually called reaction motion. It is exactly in this way, as we shall see later, that the jet plane makes its flight. Only, of course, it does not throw back iron balls taken from a trough, but the air, which it takes from the surrounding atmosphere.

The racer in the last boat, No.5, had another idea. Instead of building a trough, he stacked up a number of such iron balls right in his own boat. Of course, the supply of balls, in this case, cannot be so great as that in the trough, but then the boat is no longer dependent on the groove, and the passenger may, at will, get the necessary push for his boat by hurling the ball even when in airless space. Isn't this the very thing a space ship needs?

It is this very idea of reaction motion under the influence of the force of reaction of the hurled mass, which is stacked up on the moving machine, that forms the basis for space travel.

This idea is not a new one. The flight of the simplest dry-fuel rocket is based on this principle, and people knew how to hurl such rockets long, long ago. However, there is as great a difference between these first rockets and the reaction engine of a space ship, invented by Tsiol-

kovsky, as between the kite of the ancient Chinese and modern airplanes.

In the simple, dry-fuel rocket Tsiolkovsky found the prototype of the future space ship. He was ahead of his epoch, creating a reaction engine without which the realization of the age-old dream of mankind of travelling through space would be impossible.

The history of the rocket takes us back through the ages, to ancient times and ancient legends. It is not a simple story of peaceful, uninterrupted development; it is a story of leaps forward and sudden regressions, a story of dying and regeneration on a new basis.

The latest investigations in the field of rocket history show that rockets were used in Russia for military purposes as far back as the first half of the 10th century, 1,000 years ago. However, it may be assumed that rockets were used even before then, in Greece and very likely in ancient China. Descriptions of the flying fire-arrows used by the Chinese clearly show that these arrows were rockets. According to available data, it was from China that rocket weapons spread to other countries.

Chinese fire-arrows differed from the usual ones in that a tube made of thick paper, open only at one end and filled with a combustible substance, such as powder, was attached to the arrow. The charge was ignited and the arrow then shot off with a bow. The heated gases that formed when the charge burned escaped through the back end of the tube at a great speed, leaving a fiery trail. The force of reaction of the escaping gases increased the speed and distance of the arrow's flight, as well as the force of its impact when it hit its target. Furthermore, their burning charges started fires. These arrows were used in a number of cases, as when besieging fortifications, against ships, cavalry, etc.

However, after this first birth of rockets, they were forgotten and no further mention of their use as arms in the Middle Ages is to be found.

The second birth of military rockets dates back about 150-200 years.

Such rockets appeared in Europe at the beginning of the 19th century. They were taken over by the English from the Hindus, who had probably preserved the ancient Chinese secrets. According to available data, rocket weapons were very widely used in India at the end of the 18th century; there were special rocket detachments, whose number totalled about 5,000 people.

At the end of the 18th century, when the English invaded India, these detachments, as the English themselves admitted, caused them many "unpleasantnesses" with their rocket arrow-projectiles, which were in the form of a tube containing a charge of some combustible.* One of the English leaders, Congreve, spoke of the "stupendous" action of these projectiles. On his return to England Congreve started producing similar projectiles. By the beginning of the 19th century reaction artillery was included in the armaments of most European states.

General Alexander Zasyadko, who had received a Suvorov training, produced Russian war rockets. They were first used by the Russian army in the Caucasus in 1825 and, later, during the Russo-Turkish war in 1828-1829.

About the middle of the 19th century Artillery General Konstantin Konstantinov, a talented engineer and inventor, was unusually successful in perfecting the rocket. His work on *War Rockets* was translated into many languages, and for many years served as a reference book for artillerymen.

The machines used in rocket production, made by Konstantinov (they were called "Konstantinov machines"), did away with the dangerous and unproductive hand labour of filling the rockets, and quickly spread throughout Europe. Konstantinov rockets were the best in their day, and were effectively used during the famous defence of Sevastopol, in 1854-5.

Konstantinov also did much for the production of rocket arms and for the development of methods of using them in war-time.

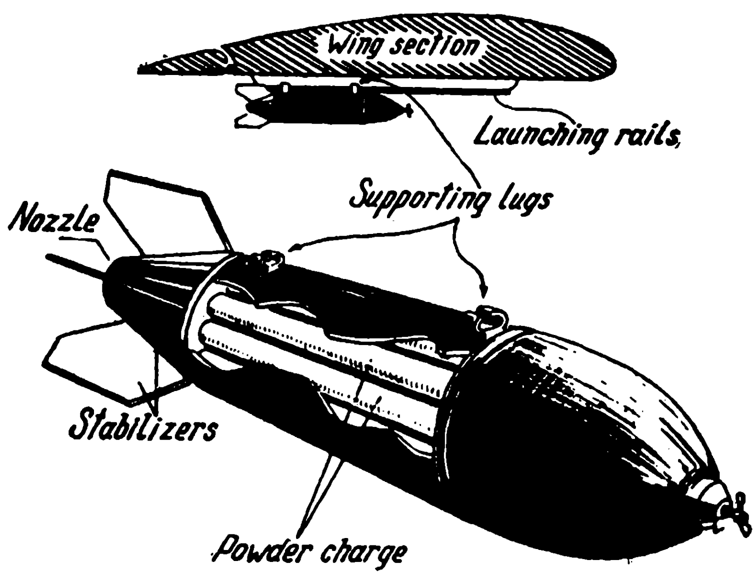
Rocket artillery was widely used in Europe up to the end of the past century. For instance, it was still used during the Turkestan campaigns of the Russian army in the 1880s. This may be attributed to the superiority of rockets over the usual type of smooth-bore guns as regards weight and mobility. As with the smooth-bore guns, however, both the distance and accuracy of fire of the rockets were poor.

In the second half of the 19th century rocket guns quickly began to give way to the rifled artillery gun, which made its appearance at that time and which fired oblong projectiles of the modern type. The rotation of

* These tubes were made of iron, and stabilizers, bamboo poles 3 m. long, were attached to them. These rockets weighed 5 kg., and could fly a distance of more than a kilometre.

these projectiles during flight greatly increased their firepower as compared with cannon balls. By the end of the 19th century rocket artillery was eliminated from the list of armaments. And in the first wars of the 20th century, as well as during World War I, 1914-18, they were not used for military purposes. Rockets were employed merely for fireworks, signalization and other purposes of a secondary nature.

The third birth of rocket armaments, which was accompanied by their rapid development, took place before our very eyes, during World War II. The whole world knows of the glorious military achievements of the "Guards" mortars, which the Soviet people affectionately called "Katyusha."



Plan of an aviation reaction projectile.

The reaction projectile begins its flight when the dry-fuel rocket motor is started. A charge made of a specially prepared powder is kept in the combustion chamber of this motor. Usually the powder is preserved in the chamber in the form of one or more powder cartridges. When, after the motor is started, the powder is ignited and then burns gradually, the incandescent gases formed as a result of the combustion escape from the motor through a nozzle, moving backwards at a tremendous velocity, which sometimes reaches 7,000 km. per hr. The force of reaction of this stream of escaping gases pushes the projectile forward, making it fly at a great speed. In other words, we see the application here of the same principle as that used by boat No.5, which took part in the race described above. Only instead of using iron balls, a supply of powder was placed in the reaction motor of the projectile and, instead of those balls, particles of the gases formed during the burning of the powder are hurled back to create the motive force of reaction.

Inasmuch as powder does not require air in order to burn, the dry-fuel rocket * motor might seem to be fully suitable for installation on an interplanetary ship. However, such is not the case. The dry-fuel rocket works as long as the powder burns, which is usually seconds or even a fraction of a second. It is obvious that this is not sufficient for space travel. Clearly, it is not enough simply to find a suitable reaction motor; we still have to make it work long enough. But the motors of jet planes work many hours at a stretch. Isn't it possible to install them on space ships?

Chapter 5

THE SOUND BARRIER IS BROKEN THROUGH!

The idea of using reaction motors for land and, later, for air transport is by no means a new one.

When the conquest of the air ocean was undertaken, inventors often turned their attention to the reaction motor. The reason for this was the need for a sufficiently light, powerful and reliable motor for dirigibles and airplanes, the lack of which delayed the development of aeronautics and, later, aviation.

The Russian inventors, Tretessky and Sokovnin, proposed using the reaction principle in aeronautics. In 1849 Tretessky presented a design of an aerostat which was set into motion by the force of reaction of a stream of steam or gas that escaped, under pressure, from an opening in the stern of the aerostat. Sokovnin, in 1866, developed a design of a similar, although somewhat improved type; in his explanations accompanying the design he said that "the airship must be able to fly the way a rocket flies."

Nikolai Kibalchich also thought of building heavier-than-air aircraft with a reaction motor. His name is well known and dear to the Soviet people as that of a revolutionary, a person who gave his life for the cause of the revolution. As is known, Kibalchich was executed by the tsarist government along with other members of the Narodnaya Volya (People's Will) Party, for their participation in an attempt on the life of Tsar Alexander II, on March 1, 1881. Kibalchich was at the head of a laboratory belonging

* Motors having this particular characteristic are called rocket motors. Motors which cannot work without air since they use the oxygen of the air to ignite the fuel, are called air-reaction motors. We speak about them in the next chapter.

to the Narodnaya Volya, and it was he who made the bomb that killed the Tsar.

It was very likely when working on this bomb, maybe earlier, that he came upon the ideas which, when confined in the death-cell, he outlined in a report which he sent to the tsarist government several days before his execution. Kibalchich proposed building a heavier-than-air aircraft using a dry-fuel rocket motor which he had designed. This idea of the 27-year-old revolutionary was far ahead of its time, but the tsarist government, as was to be expected, would not even consider his proposal. Judging from the decision written on Kibalchich's report, the tsarist government considered it undesirable to draw attention to the fate of this convicted Narodovolets,* although when writing his report Kibalchich had absolutely no intention of asking for pardon or even for a delay of his execution; he simply wished to meet other scientists and tell them about his idea. Kibalchich was executed, and only 36 years later, in August 1917, was his report discovered in the police archives.

The attempts made at the beginning of our century to install dry-fuel rockets in automobiles, motor-cycles, gliders and other means of transportation were rather frequent, but most of them were of an advertising or sports nature. They were of no practical significance, for the chief defect of the dry-fuel rocket motor, namely, the insignificant duration of its operation, could not be overcome.

This defect is an inherent characteristic of the dry-fuel motor, for the entire fuel supply, the powder, must be placed in the combustion chamber beforehand, which greatly limits the amount of fuel that can be stored. The delivery of additional supplies of dry fuel to the combustion chamber is fraught with exceptional difficulties, and in spite of the large number of proposals of this type by inventors, including that of Kibalchich, to this day this problem has not been solved.

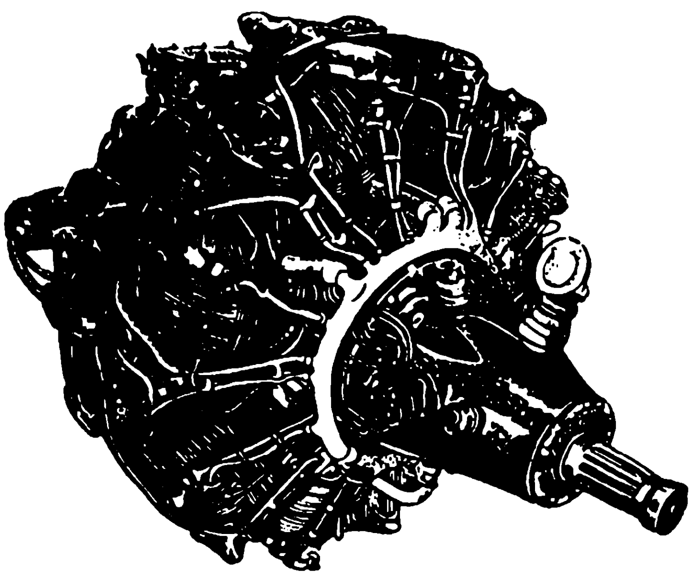
However, as aviation continued to develop, the need for a new motor for airplanes, one which could ensure unprecedented flight speeds, was felt more and more keenly.

To increase the flight speed was one of the most important tasks that had always faced aviation. Not without reason do airmen say: "He who is

* Member of the Narodnaya Volya (People's Will) Party.

quicker in the air is stronger in the air." From the moment Mozhaisky's plane made its first flight, down to our very day, there has been a constant striving, the whole world over, to increase the flight speed. And whereas the first planes flew at a speed of 40-45 kilometres an hour, at the beginning of the past war their velocity had already increased to 700-750 kilometres an hour. What tremendous progress!

Throughout all these years the piston internal-combustion aviation engine, by means of which the propeller is set in motion, rendered faithful service. It was the only type of motor that was used in aviation. This engine had greatly developed since the first plane took to the air. Its power increased from several tens to several thousand horse-power. Its design was greatly improved—it became more compact, lighter. And the economy of its operation considerably increased—it began to consume much less fuel per horse-power. Furthermore, its reliability became extraordinary—it acquired the ability to operate uninterruptedly for many hundreds of hours at a stretch.



Soviet piston aviation motor ASh-82.

The piston aviation motor became a highly perfected machine, one of the remarkable achievements of technique and of human genius. Who doesn't know of the brilliant air victories won with the aid of this motor—the historical flights of Chkalov and Gromov over the North Pole, the high altitude flights of Kokkinaki and many others!

And in spite of all this, by the end of World War II the glory of the piston engine had begun to fade: it was felt more and more strongly that this motor was becoming an obstacle for the further development of aviation. In spite of the indisputable merits of the piston engine, its chief defect was beginning to make itself clearly felt—it was unsuitable for flights at such velocities as were now demanded of aviation. No improvements in its design could correct this defect. The engine simply "gave up"

in the face of the new speeds. And its replacement by a motor of another order became inevitable.

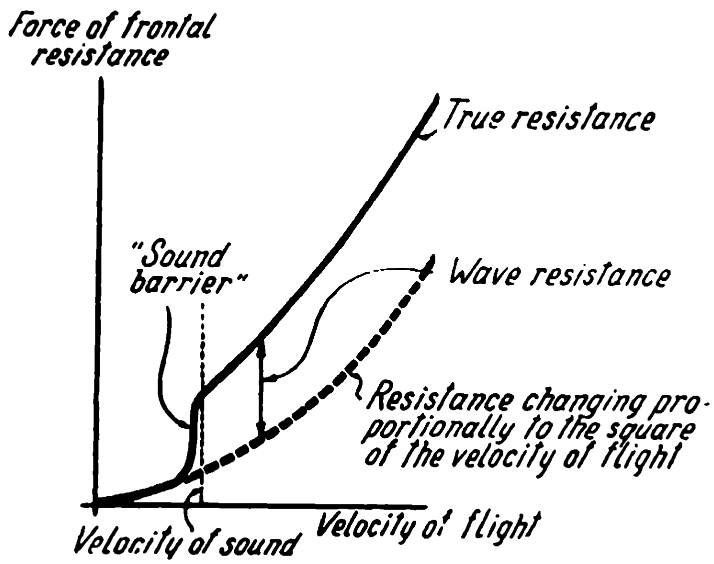
When a plane flies at an ever-increasing velocity, it has to overcome the ever greater resistance of the air. But this means that the air motor must develop more and more power, since the work it does is spent on overcoming the air resistance. Unfortunately, the piston aviation engine develops practically one and the same power irrespective of the flight velocity. If, when at the aerodrome, the engine can develop, let us say, 2,000 horse-power, it will develop this same 2,000 horse-power during flight, even when the plane is rushing along at a speed of 600 or 700 kilometres an hour. If a more powerful engine were to be installed, it would be heavier, which in turn would mean a larger airplane and, consequently, the demands made of the engine would be correspondingly greater. It is a vicious circle from which there is no way out for the piston engine.

Besides this, the piston engine's constant companion, the propeller, also began to fall down on its job. As the flight speed increases, the ends of the propeller blades, which make a very great number of turns, begin to move in the air at such a tremendous velocity that the work of the propeller loses much of its effectiveness. The greater part of the engine's power is lost with such a propeller because of the increase in the losses connected with the compressibility of the air, and an ever smaller part of this power is spent on the useful work of moving the plane in the air. Yet with the increase in the flight velocity, the need for such useful work becomes ever greater.

Finally, one more obstacle was discovered, which definitely put an end to the piston engine. An ominous, invisible wall arose to prevent increasing the flight speed of airplanes—the sound barrier.... This mysterious "threshold" worried the minds of aviation specialists; it was the subject of ever more articles in technical journals and of an increasing number of scientific investigations. It seems that as the flight speed increases, as was proved by experiments in aerodynamic tubes, the resistance which the air offers the flying plane begins to increase suddenly and sharply. As if some invisible hand suddenly pushed up against the nose of the flying plane and prevented it from moving at a greater velocity, retarding it. The greater the velocity of the flight, the stronger this hand, and the greater must the power of the airplane engine be to overcome this braking force. The

power of the piston motor is insufficient as is, and here, to make a bad matter worse, we have this additional trouble.

As had frequently been the case in many other instances, the reasons for this sudden increase in the resistance of the air with the increase in the flight velocity had not only been foretold long before the planes began to feel it during flight, but had even been subjected to most thorough theoretical investigation.



"Sound barrier."

Back in the 19th century N. Maievsky, Professor at the Artillery Academy, first pointed out the connection between this unexpected increase in resistance and the velocity of sound in the air, that is, the velocity with which sound-waves travel through the air. In 1902 a brilliant scientific study was published, the work of Sergei Chaplygin, then still a young scientist, later a member of the Academy, and pupil and friend of Nikolai Zhukovsky. This investigation laid the foundation for the theory of flight at velocities approximating the velocity of sound. For over a third of a century this outstanding work of Chaplygin's remained practically unnoticed, and was regarded merely as an original mathematical research, until the development of aviation advanced problems which proved to have been solved, to a large degree, by the work of this Russian scientist.

It is now a well-known fact that as the flight speed of a plane approaches the speed of sound in the air, which is approximately equal to 340 metres per second, or 1,225 kilometres per hour, * the resistance of the air increases. As the flight speed more closely approaches the speed of sound the greater is this additional, so-called wave resistance. At the same time

* At the Earth, at the usual temperature of the air. This speed is directly proportional to the square root of the temperature of the air and, consequently, decreases as the altitude of the flight increases.

the flight itself becomes unsteady, the plane begins to vibrate, and its management becomes more difficult.

Soviet scientists, specialists in the field of aerodynamics, using Chaplygin's ideas, had much work ahead of them before they succeeded in finding a means of diminishing the unpleasant features connected with a flight whose speed approximated the speed of sound. The results of these studies are the unusually thin wings of speed planes,* the unusual form of these wings, which make a modern speed plane look like a whirling arrow, and many other specific features of these machines.

Profile of the wing of the supersonic airplane proposed by K. E. Tsiolkovsky.

It became clear, once and for all, that, with the usual piston engine it would be impossible to exceed the speed of sound, to break through the sound barrier. Aviation, therefore, turned to reaction technique for help.

This was the one and only logical step to take, for reaction motors are the most effective for high speed flight. It is easy to convince oneself of the truth of this statement merely by looking at the dry-fuel rocket.

Imagine such a rocket being tested on the test stand. The motor works, the powder burns; incandescent powder gases escape through the nozzle of the rocket, but it is all in vain, for the motor is not doing any useful work while all this is going on. And indeed, work is the action of a force along a certain path, and in the given case we have a force, the force of reaction of the stream of escaping gases, but no path—the rocket is immobile. It is the same as if, let us say, you were ordered to move a heavy case to one side, about two metres. No matter how hard you laboured, trying to move this box, you would not be accomplishing any useful work as yet. But, if the box did move from its place, then work would actually be accomplished, the work equivalent to the product of your efforts and the path traversed by the box. So long as the box remained immobile, the energy you expended would be lost.

* Characteristic of the wide range of Tsiolkovsky's scientific interests is the wing profile of the supersonic airplane, proposed by him, the so-called double-edged wedge (see figure on this page), which will very likely be widely used in the future, in particular for the wing of a space ship making a gliding landing in the Earth's atmosphere.

But there, the rocket has flown off and is whirling along at an increasing velocity. Now the rocket is really performing work, which is equal to the force of reaction of the stream of gases multiplied by the path traversed by the rocket.

The greater the flight speed, the greater the useful work. It is easy to calculate when the energy of the gases will be fully used to perform productive work, that of moving the rocket in its surrounding medium. Apparently at that moment when the flight speed of the rocket will be exactly equal to the jet velocity. Indeed, in this case the gases escaping from the rocket at a tremendous speed will be, as far as the air surrounding them is concerned, absolutely immobile. This also means that the gases have lost all their kinetic energy, which has become transformed into the useful work of moving the rocket. True, in order for such a moment to become possible, the dry-fuel rocket must fly at a very great speed, about 6,000-7,000 kilometres per hour, but the closer the flight speed approaches this most useful speed, the more effective becomes the work of the reaction motor.

And so we see that the reaction motor is indeed meant for great velocities. For this very reason reaction motors will probably never be widely used in transport on land and water—on railways, in automobiles and boats. At relatively low travel velocities, such as are possible in these cases, the reaction motor is at a disadvantage and yields its place to the internal-combustion piston engine we have spoken of above. The situation is altogether different in the air, where tremendous velocities are possible, in aviation and the artillery. In such cases the reaction motor is unrivalled. This is especially true as regards airless, interplanetary space. Incidentally, the first to draw the conclusion as to the advantage of using reaction motors at great flight speeds was also Tsiolkovsky.

So long as the flight speed of planes was relatively low, aviation could get along fully well with the piston engine, whereas the use of the reaction motor would be unprofitable. But when the velocity increased greatly, the piston engine began to give way and all eyes became focussed on the reaction motor.

However, the aircraft reaction motor must, apparently, differ in many respects from the motors of reaction artillery, first of all because it must ensure a flight of long duration. The work of the aircraft reaction motor must now be measured not in seconds, as with the dry-fuel reaction motors,

but in hours. In this case it is impossible to store all the fuel in the combustion chamber, as in the dry-fuel motor, but it will have to be delivered there in small portions. It, therefore, follows that the fuel for the aviation motor must not be solid. But that is still not all—such a motor must expend little fuel, that is, it must be economical in order that the usual supply of fuel on the airplane be sufficient for a prolonged flight.

There are motors that satisfy these demands. They are the so-called air-reaction motors. They operate not on dry, but on liquid fuel, and use the oxygen in the atmosphere for combustion. As a result of this, the duration of their work is immeasurably greater than that of dry-fuel motors.

The first designs of air-reaction motors appeared in many countries, including Russia, back in the nineteenth century. In 1867, N. Teleshov, a Russian inventor, patented an air-reaction motor with a compressor for compressing the air. He called this a thermal gas jet motor.

In May 1884 the inventor Yakubinsky submitted to a meeting of the aeronautical department of the Russian Technical Society the first design for an air-reaction motor meant especially for flying machines.

Kuzminsky, a talented engineer and inventor, back in 1897, built and tested on a cutter on the Neva River the first gas-turbine engine ever produced; its construction was very much like that of motors in modern jet aircraft.

Interesting projects for air-reaction motors were developed at the beginning of the twentieth century by inventors Karavodin, Antonovich, Gorokhov and Nikolsky.

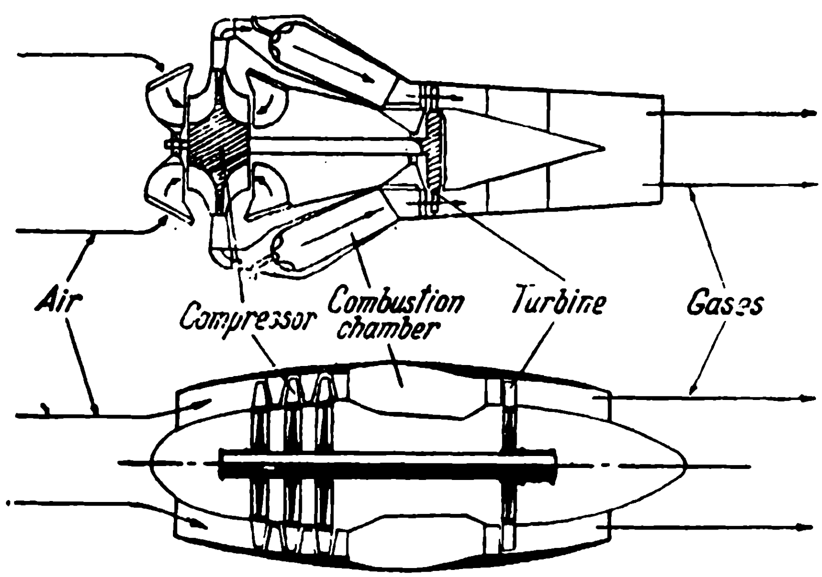
In 1924 designer Bazarov received an author's certificate for the design of a so-called turbo-propeller motor for aircraft, in which the thrust is effected by means of a propeller operated by the turbine, and by the reaction of the stream of escaping gases. The motors in modern jet planes borrow many of their chief features from this project.

Tsiolkovsky, who had also worked on the problem of using reaction motors for aviation, in 1932 proposed the so-called double-contour turbo-reaction motor. The design of such a motor was developed in 1937 by engineer Lyulka.

In Russia, too, the principles governing the theory and calculation of jet motors were formulated. At the end of the nineteenth century Nikolai

Zhukovsky, in his famous works on *The Force of Reaction of an Outflowing and Inflowing Liquid* (1882 and 1886), supplied the formula for the determination of the thrust, which formula is used today all over the world. Academician B. Stechkin, who had studied under Zhukovsky, was the first to formulate a theory for air-reaction motors, published by him in 1929.

Whereas the dry-fuel reaction motor astonishes one because of its simplicity and the fact that it does not have a single mobile part, the turbo-reaction motor of the modern jet airplane is a rather intricate machine. However, both of these motors have one and the same aim: to develop a reaction thrust, which is created by gases escaping from the motor.



Schemes of turbo-reaction motors: above—with centrifugal compressor; below—with axial.

The air, when coming into the turbo-reaction motor through the air-inlet funnels, is compressed in it to a pressure of several atmospheres. There is a special machine, the compressor, which is used especially for this purpose. It may be a centrifugal compressor, which is a winged apparatus of large diameter, making a large number of revolutions, or it may be an axial compressor. The latter derives its name from the fact that the air, when compressed in it, flows parallel to the axis and not along a radius from the centre to the periphery, as is the case in the centrifugal compressor. The axial compressor is a series of wheels with blades on the felly, the wheels rotating between rows of immovable blades.

The fuel, most frequently ordinary kerosene, is injected into the compressed air in the combustion chamber of the motor. The products of combustion of the fuel—the heated gases—enter the gas turbine and expand in it, transmitting part of their energy to the turbine blades. As a result of

this, the turbine rotates, developing the power necessary to set the compressor into operation. It is for this purpose that the turbine is in the motor, and it is, therefore, connected to the compressor by a strong steel shaft. This shaft must indeed be strong, for in the most modern turbo-reaction motors the power of the turbine and the power of the compressor, which is practically equal to it, at times already exceeds 50,000 horse-power.

The gases that escape from the motor through the reaction nozzle have a considerable velocity, much greater than the flight speed. It is this difference in velocities that causes the force of reaction or the reaction thrust of the motor. The force of reaction of the stream of gases escaping from the motor is the force which makes the jet plane fly at a great speed.

The turbo-reaction motors used in army planes now develop a thrust of four-five tons and more. It is easy to calculate what power a motor of such thrust develops during flight. For instance, the power of a motor having a thrust of 4,000 kilogrammes at a flight speed of 300 metres per second, which is the same as 1,080 kilometres per hour, is equivalent to 16,000 horse-power.

And this, at a time when the most powerful piston aircraft motors develop a power which is one-fourth of this, to say the least. But that is not all: about a fourth of all the power developed by the piston motor is lost by the propeller so that when the power of the motor is 4,000 horse-power, the useful power is about 3,000 horse-power. At the same time, such a motor is larger in size and weight than a turbo-reaction motor, that is from five to six times more powerful. Therein lies the secret of the success of reaction motors in aviation.

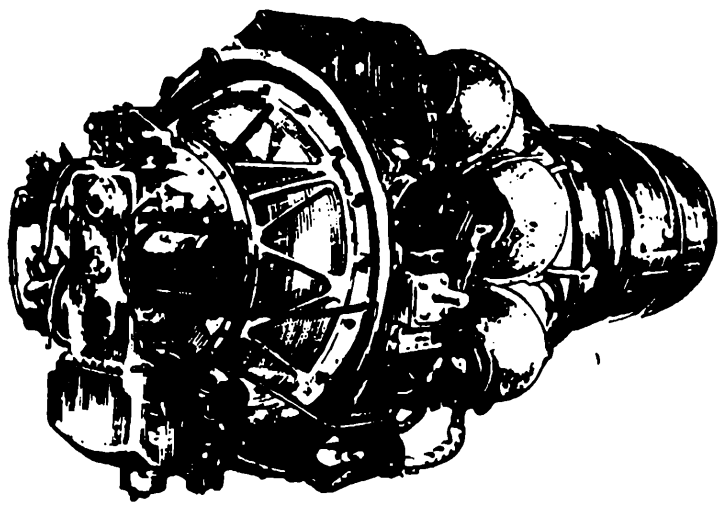
And this success, we may say, is indeed extraordinary. During the few years that have elapsed since the end of the war, all high-speed aircraft throughout the world has become jet aircraft. We can unhesitatingly speak of the technical revolution in aviation as a result of the application of reaction motors.

While on this subject we cannot help but recall, with justified pride, Tsiolkovsky's prophetic words, pronounced at a time when the mere idea of constructing reaction aircraft was regarded as wild fantasy: "An era of reaction airplanes must follow the era of propeller airplanes." These prophetic words, expressed a quarter of a century ago, have now come true. We are living in a period when reaction aircraft is in its bloom.

Today jet-propelled passenger airplanes already fly at a velocity approximating the velocity of sound, and soon passengers will spend more time on a trip from town to the aerodrome than, we may say, on a flight from Moscow to Leningrad.

What is more, many planes already fly with the speed higher than that of sound. The sound barrier has been overcome!

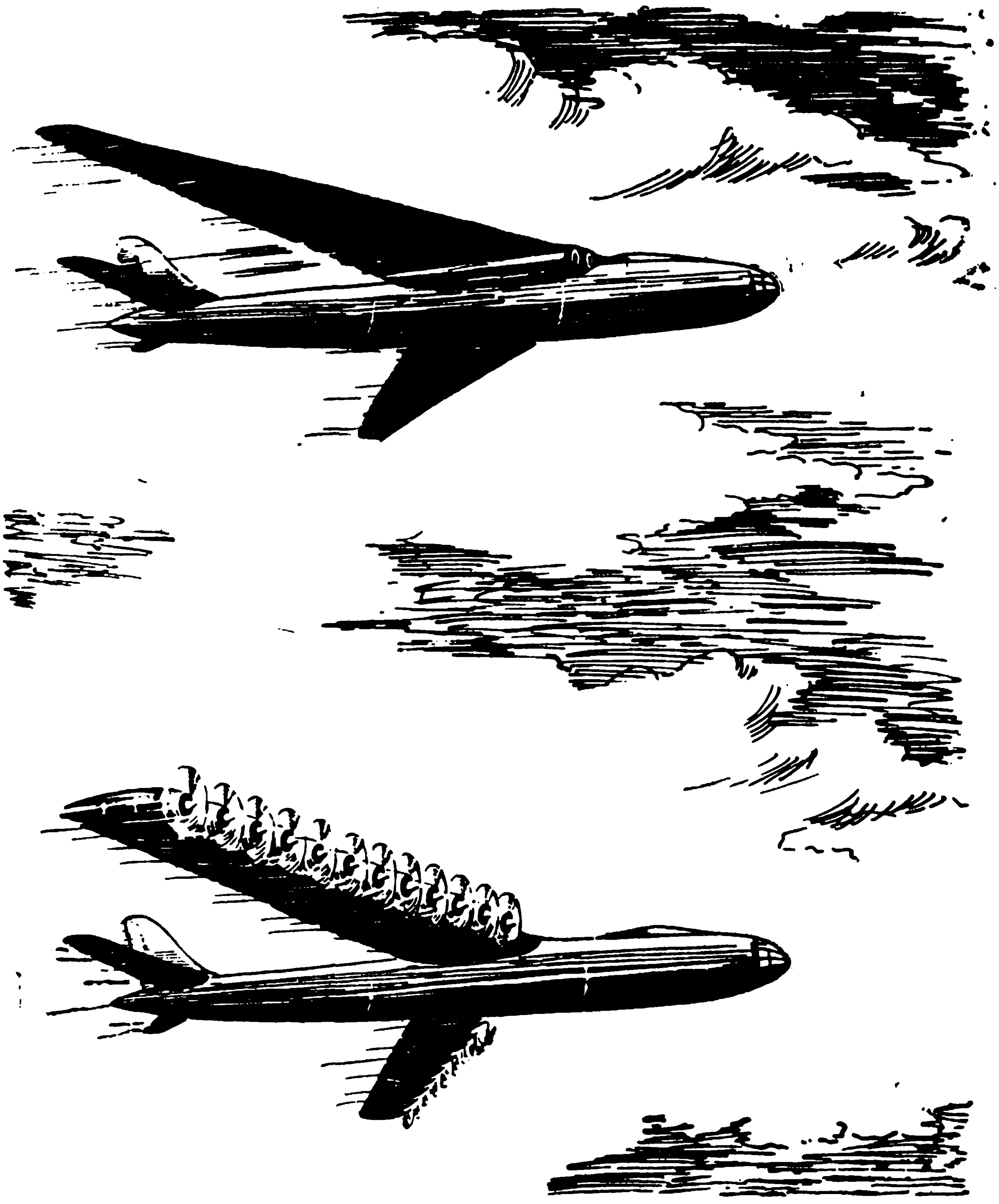
But these achievements on the part of air-reaction motors in aviation are only the first steps. There is an even more brilliant future awaiting them, even greater flight speeds: 3,000-4,000-5,000 kilometres an hour. And what is most interesting, at such great flight speeds the motor will not only not become more intricate, but, on the contrary, will be simplified to the utmost.



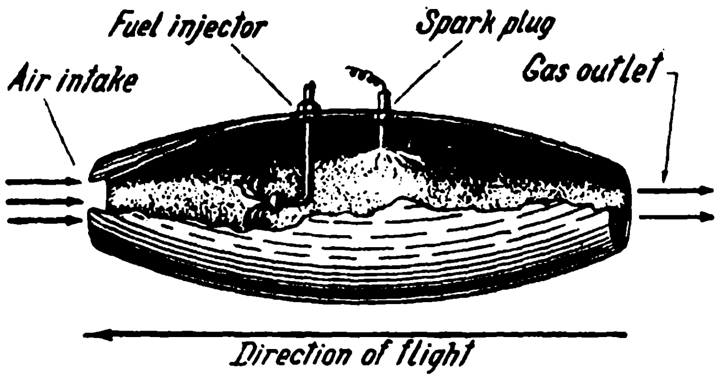
Turbo-jet motor with centrifugal compressor RD-500.

The intricacy of a turbo-reaction motor is connected chiefly with its mobile, rotating parts, the compressor and turbine. On the one hand, they lessen the reliability of the motor; on the other—they limit the possibility of further increasing the thrust, which also means—the possibility of further increasing the flight speed. Unfortunately, however, we cannot get along without the compressor and, it follows, without the turbine; in order for the motor to operate, developing great thrust and expending little fuel, the air must be compressed and its pressure in the combustion chamber must be increased. When flying at a speed two or three times greater than the speed of sound, the compressor becomes superfluous: we can obtain the necessary high air pressure in the motor without its aid.

The secret here is simple. Why is it, when leaning out of a car window of a fast moving train, when coming down a steep hill on skis, or when making a swallow dive from a spring-board, one feels that the air becomes resilient? What is it that takes our breath away in such cases? What force hits us in the chest and face so powerfully? Why does an ordinary wind become so terrible when, with the force of a hurricane, it attacks the trees,



Instead of four turbo-reaction motors of the modern jet bomber, no less than 24 super-powerful piston motors would have to be installed.



Scheme of uniflow air-reaction motor.

buildings, people, tears the roofs off houses and overturns railway cars?

This force originates when the impetuously whirling air is stopped by some unexpected obstacle, when it suddenly, sharply comes to a standstill, interrupting its mad run. All the power, all the kinetic energy of the air, in these cases, is spent on its compression, on increasing its pressure, creating the so-called speed pressure. It is this that throws people off their feet and uproots trees.

What happens when a jet plane whirls through the air at a tremendous speed, quicker than that of any hurricane? The air, which rushes into the motor at this speed, almost comes to a standstill in it. It is easy to imagine how great the speed pressure of the air will be under these circumstances. And yet, even at the velocities at which modern jet planes fly, this speed pressure is still unable to create the necessary pressure in the motor; it simply helps the compressor.

But when the flight speed begins considerably to exceed the speed of sound, then, by merely using this speed pressure, the pressure in the motor can be raised to many atmospheres and even to tens of atmospheres.

When that happens, there will be no need for a compressor. It also follows that there will be no need for a turbine, and the turbo-reaction motor will be transformed into a fire-box flying at a tremendous speed, a flying funnel with no mobile parts whatever. And in spite of all this simplicity, such a uniflow air-reaction motor, at these great flight speeds, of the same dimensions and of much smaller weight than that of the modern turbo-reaction motor, will develop a thrust that is tens of times greater and will expend much less fuel.* It is, therefore, not surprising that so much attention is now being devoted to uniflow motors in order that these motors may be widely used in the supersonic aircraft of tomorrow.

* A defect of such a motor is that it does not develop thrust when the plane is standing still and therefore, cannot ensure its take-off; some other supplementary motor must be installed in the plane for this purpose.

The development of aviation reaction technique has already led to the creation of air reaction motors that are powerful, economical, light, and able to work for hundreds of hours at a stretch. They would be wonderful motors for the space ship if... if they were fit for this purpose at all. But they are not, of course, suitable, for the motors need air for their operation (for the burning of the fuel), and this is the very thing that is not to be found in space.

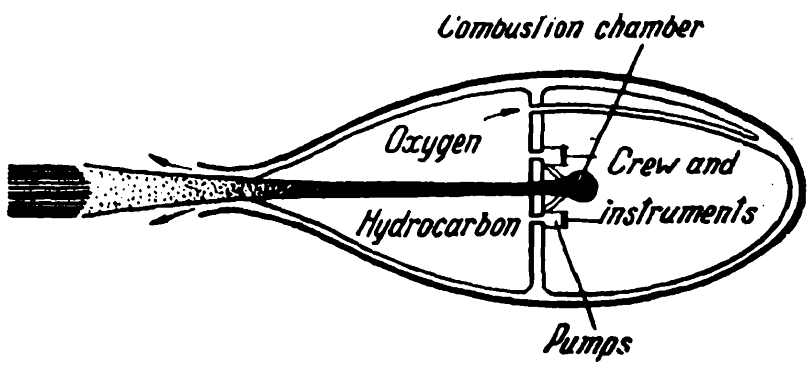
It follows, that a space ship needs a reaction motor combining the ability of a dry-fuel motor (able to operate without air) and that of an air-reaction motor (able to operate for a long time). It was this kind of a motor that Tsiolkovsky invented.*

Chapter 6

HARNESSING HALF A MILLION HORSES

Tsiolkovsky became interested in the problem of space travel and reaction motion, which was connected with it, back at the end of the past century. An article written by him in 1883 but not published, entitled "Free Space," has been found among his papers. The article discusses the principles governing reaction flight in space.

In 1896 Tsiolkovsky began a narrative called *Beyond the Earth*, in which he describes a rocket which serves as an interplanetary ship.



Scheme of K. E. Tsiolkovsky's interplanetary ship with liquid-fuel rocket motor.

Tsiolkovsky's first printed work on rockets as a means of effecting space travel appeared in 1903. It was an article called "Exploration of Space with Reaction Instruments," published in the journal *Nauchnoye Obozreniye* (*Scientific Review*), No. 5, 1903. The appearance of this article marked the official birth of a new science, the science of rocket astronautics. After numerous reprints of this

* It should be mentioned that Tsiolkovsky invented this motor before the first air-reaction motors were built.

article it was renamed, beginning with the year 1924, "The Rocket in Cosmic Space."

Besides formulating the theory of space travel, Tsiolkovsky, in this article, outlined a design for a space ship with a new type of reaction motor which he had invented. It is this very motor that will decide the problem of cosmic travel, for it alone happily combines all the contradictory requirements that are demanded of a motor for interplanetary ships. It is the so-called liquid-fuel rocket motor.

The latter, like the dry-fuel rocket motor, does not require air for its operation and, consequently, can function also in airless space and even better than in the atmosphere. Furthermore, it can operate for a much longer period than the dry-fuel motor, for, as its name suggests, it operates on liquid fuel, not on dry, and this liquid fuel can be gradually supplied to the combustion chamber from tanks. It is this idea of using liquid fuel in the rocket motor that makes this invention of Tsiolkovsky's so remarkable. This idea is being widely used not only in liquid-fuel rocket motors, but also in the air-reaction motors, about which we told you in the preceding chapter.

However, the fuel for liquid-fuel rocket motors does not consist of one liquid, as gasoline for piston motors, or kerosene for turbo-reaction motors, but usually consists of two different liquids. Each of these liquids is preserved in a special tank or compartment of the ship, as shown in Tsiolkovsky's scheme, and only the two combined form the fuel.

One of these liquids is the so-called combustible. As you see, in the given case combustible and fuel are not one and the same thing: the combustible is only part of the fuel.

The role of the combustible in this case is the usual one; when burning it must give off heat, which is necessary for the operation of the liquid-fuel rocket motor. The usual oil combustibles, such as gasoline and kerosene, also alcohol, aniline and other substances are used as the combustibles (in Tsiolkovsky's scheme of the ship combustible compartment is marked "hydrocarbon").

It is easy to guess what liquid is to go into the other tank on the rocket with a liquid-fuel rocket motor. For the combustible to burn, oxygen is necessary. Where is it to be obtained if it cannot be taken from the surrounding atmosphere? Obviously the other tank must contain a liquid which has a sufficient quantity of oxygen or a so-called oxidizer. Such liquids as strong

nitric acid, hydrogen peroxide of high concentration and others are used as oxidizers. Pure oxygen, suggested by Tsiolkovsky, is also widely used, not, of course, in its gaseous form (the tank could contain very little, besides which, it would have to be very durable), but in liquid form. In order to be liquefied the oxygen must be cooled to a temperature of 183°C below zero.

Both parts of the fuel, the combustible and the oxidizer, are delivered to the combustion chamber of the motor under high pressure. This pressure, which reaches tens of atmospheres, can be created, for instance, by some gas flowing into the fuel tank from the high-pressure tank in which it is contained. Fuel delivery may be effected also with the aid of special pumps, as indicated in Tsiolkovsky's scheme.

The component parts of the fuel meet in the combustion chamber and here the chemical reaction of combustion takes place. A tremendous quantity of heat is given off during this process, so that the temperature in the combustion chamber becomes very high. It is the highest temperature ever obtained in motors, in some cases exceeding 3,000°C. The heated gases, the products of this combustion, escape from the motor via the nozzle at a tremendous velocity which reaches 2.5 kilometres per second and even more.

It is natural that the force of reaction of the stream of escaping gases, which is the reaction thrust of the motor, is very great, for this force is directly proportional to the jet velocity of the motor. It is the reaction thrust that must impart to the space ship the required high velocity.

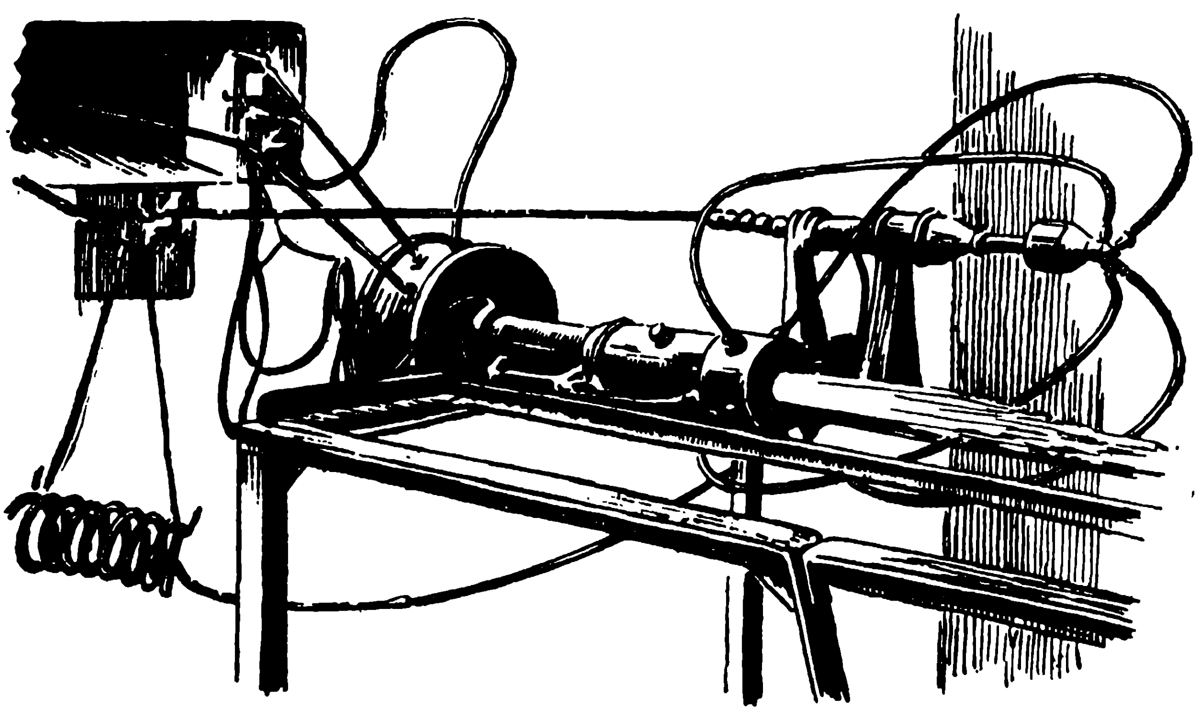
During the half a century that has elapsed since Tsiolkovsky invented the liquid-fuel rocket motor, it has traversed a great path of development. The first decades were marked chiefly by the persistent labour of individual inventors, enthusiasts, and their modest attempts to build a liquid-fuel rocket motor for use in rocket flight. Today we already have many tested, reliable designs of such motors. They are installed in various aircraft and rockets, and are used for the most diverse purposes. Scientific research institutes and groups of designers are at work on this problem. A new branch of industry for the production of liquid-fuel rocket motors and flying machines with such motors is growing up.

As in the case of other branches of reaction technique, Russia has done much to further the development of liquid-fuel rocket motors.

Somewhat later than Tsiolkovsky and quite independently of him, the talented investigator and self-taught inventor, Y. Kondratyuk, began working on the problem of space travel and, in this connection, in the field of reaction technique. In addition to the theory of interplanetary flight, which he discussed in his works, Kondratyuk came out with a number of original ideas regarding the perfection of liquid-fuel rocket motors. In particular, he, independently of Tsiolkovsky, who first suggested this idea, proposed using ozone instead of oxygen as the oxidizer, an idea which today holds forth great promise.

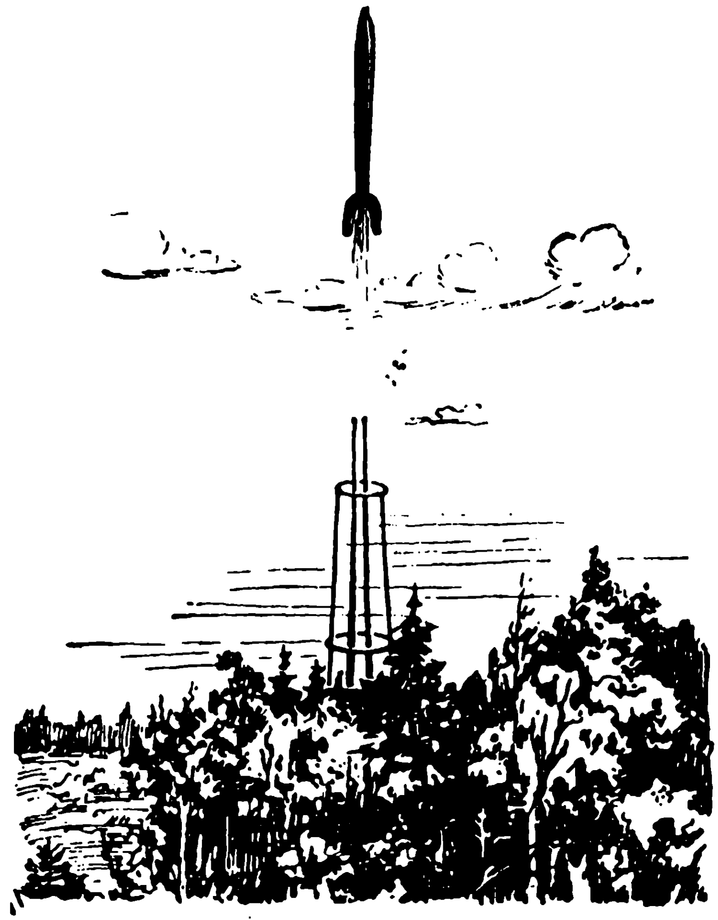
F. Tsander, who supported and followed up Tsiolkovsky's ideas, also contributed greatly to the development of liquid-fuel rocket motors. He was the first engineer in the Soviet Union to devote himself to space travel and rocket technique. He is the author of a number of ideas contributing to the successful solution of the problem of space travel. He also made a study of many questions concerning the development and perfection of motors for interplanetary ships.

Back in 1920, when the Soviet Union was just emerging from the Civil War and was faced with the difficult tasks of restoring its ruined economy, Tsander made a report at the Moscow Conference of Inventors on his design for an interplanetary ship and a motor for it. Vladimir Ilyich Lenin then promised the inventor support in his further work.



F. Tsander's liquid-fuel rocket motor on test stand (1933).

In 1930 Tsander built his first liquid-fuel rocket motor, which operated on gasoline and oxygen from the air. This motor was essentially only a model of another, larger motor that operated on gasoline and liquid oxygen, built by Tsander in 1932. It was tried out only after Tsander's premature death in 1933. This was one of the first liquid-fuel rocket motors in the world. But even before then, in 1930, a liquid-fuel rocket engine was built by another Russian designer, Valentin Glushko. That was the first engine of its kind in the Soviet Union. It operated on fuel consisting of nitrogen tetroxide and toluene. Tsander also advanced the idea of using certain metals as combustibles for liquid-fuel rocket motors (Kondratyuk also suggested this idea independently of Tsander). This would make it possible to burn those parts of the space ship itself, which became unnecessary during the flight, as empty tanks, etc. Tsander also developed a method for calculating liquid-fuel rocket motors.



Take-off of M. K. Tikhonravov's rocket with liquid-fuel motor (1933).

On August 17, 1933, the first flight of a rocket invented by Mikhail Tikhonravov, using a liquid-fuel rocket motor, was made. Many other flights were made after this.

The year 1940 was marked by an outstanding achievement in the development of liquid-fuel rocket motors. That year a flight was made for the first time by man in an airplane with a liquid-fuel rocket motor. On February 28, 1940, a plane towing a glider plane with a liquid-fuel rocket motor took off from one of the aerodromes in the suburbs of Moscow. Flier

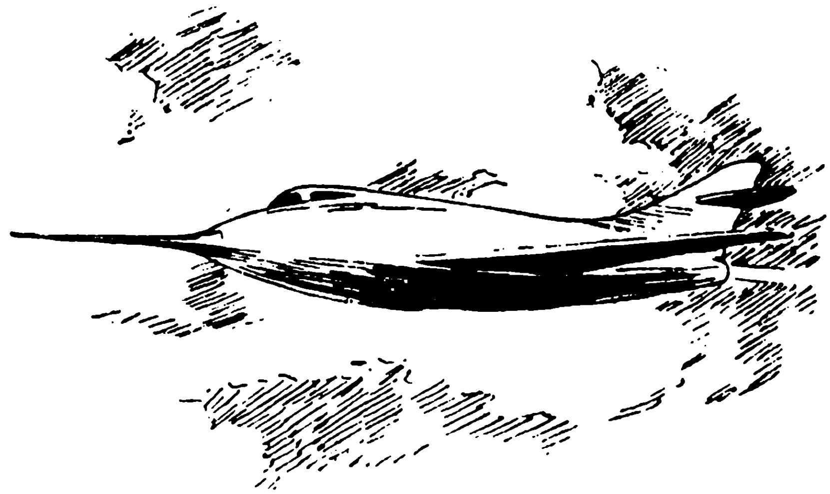
V. Fyodorov, who piloted the glider, then flew it in the air independently, turning on the motor. A new page in the development of reaction technique was begun. Slightly over two years later, on May 15, 1942, Captain G. Bakhchivanji made the first flight in a plane with a liquid-fuel rocket motor designed by V. Bolkhovitinov.

Liquid-fuel rocket motors are now used in aviation for various purposes. In many cases they are employed to facilitate the launching of heavy aircraft. Sometimes these motors are installed in planes to supplement the main motor which is of another type as, for instance, the turbo-reaction motor, for the purpose of increasing the flight speed at some necessary moment, as when gaining altitude, during an air battle, etc.

Liquid-fuel rocket motors are also installed in airplanes as the main and only motor. Planes with such motors are usually designed for purposes of exploration—to study the specific features of flight at very high, supersonic speeds. They make it possible to achieve the greatest flight speeds as yet attainable. There are also military planes with such motors, the so-called defence or intercepter fighter planes, whose task it is to combat enemy bombers.

However, planes with liquid-fuel rocket motors have a very serious defect as compared with other planes—they can remain in flight for a much smaller period. This is due to the fact that liquid-fuel rocket motors are exceptionally "greedy"—they use up from 15 to 20 times more fuel than turbo-reaction motors of the same thrust. For this reason, if the liquid-fuel rocket motor works uninterruptedly, at full power, the fuel supply on an intercepter fighter plane is sufficient for only 3-5 minutes. By alternatingly running the plane with the motor operating and then coasting, with the motor turned off, the pilot of such a plane can increase the total duration of the flight to 20-30 minutes. This is barely sufficient for him to take off, engage the enemy in battle in the region of his aerodrome, and then land with empty tanks. That is why liquid-fuel rocket motors are as yet used only in this one type of military plane, the intercepter fighter plane.

Liquid-fuel rocket motors today are to be found chiefly not in aviation, but in various kinds of rockets. These are the heavy projectiles for anti-aircraft defence, rocket aviation-bombs, long-range projectiles and stratosphere rockets.



Exploratory supersonic airplane with liquid-fuel rocket motor.

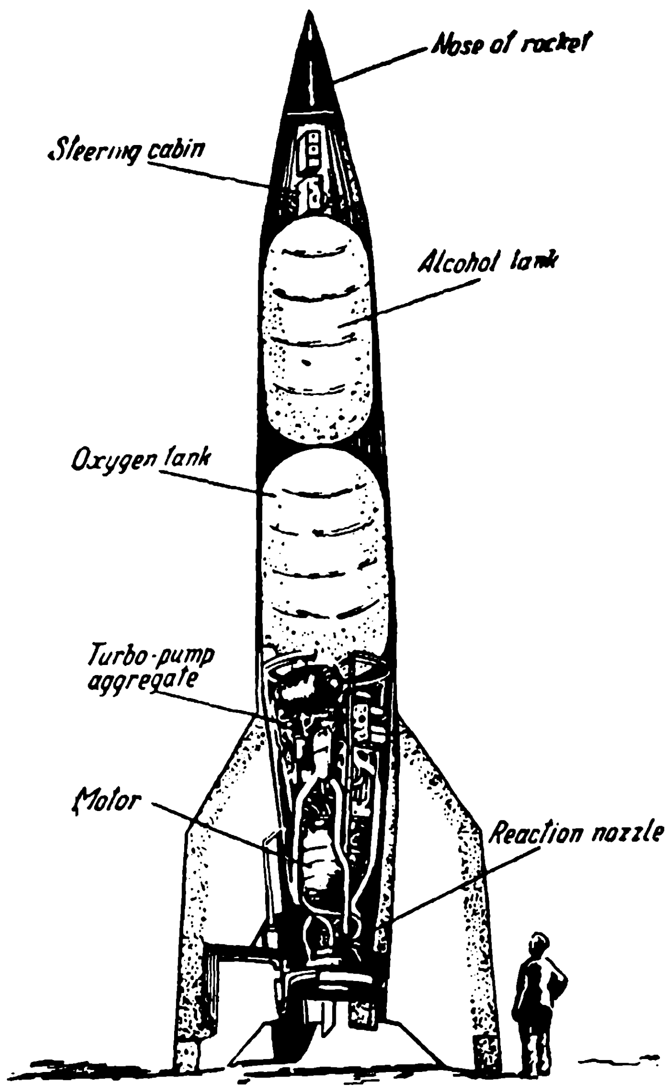
The use of heavy rockets with liquid-fuel rocket motors is becoming ever greater, and some of these rockets are already beginning to look very much like small space ships, as they are usually pictured in books.

Here is one of these rockets, used during the past war as a heavy, long-range reaction projectile (see page *58*). The war-head of this projectile contained $^3/_4$ of a ton of explosives, and the projectile flew a distance of about 300 kilometres. Of course, not a single heavy, long-range gun ever fired such heavy projectiles over such a distance. A powerful liquid-fuel rocket motor was installed in this projectile.

The rocket was about 14 metres long; its diameter was 1.7 metres, which at its tail was as much as 3.6 metres. One cannot help but be impressed by the dimensions of this rocket, when comparing them with the figures of the people standing beside it. The weight of this rocket, too, is most impressive—about 13 tons, so that the weight of the "pay-load"—the explosives—constitutes but a small part, a slight percentage, of the total weight of the rocket.

The motor is installed in the "stern" of the rocket, as it probably will be in a space ship. This motor operates on fuel consisting of two liquids. That is why two gigantic tanks have been put up in the middle part of the rocket.

The foremost tank contains the combustible which, in the given case, is ethyl alcohol (not less than 75° in strength). The rear tank contains the oxidizer—pure, liquid oxygen, as proposed by Tsiolkovsky in his day.



Plan of heavy long-range projectile-rocket with liquid-fuel rocket motor.

The fuel supply on the rocket is about 9 tons. This is what constitutes the greater part of the total weight of the rocket, about $^2/_3$ of it. Of these 9 tons about 4 tons are alcohol, the rest—liquid oxygen.

To be shot off, that is, to be launched, this rocket is set up in a vertical position, in which it is supported by means of a special light cradle. Almost like an interplanetary ship that is getting ready to take a leap into space. When in this position the gigantic tanks of the rocket are filled with fuel. Powerful automatic fuellers are used for this purpose, but they look like toys alongside the rocket, which stretches up to the sky.

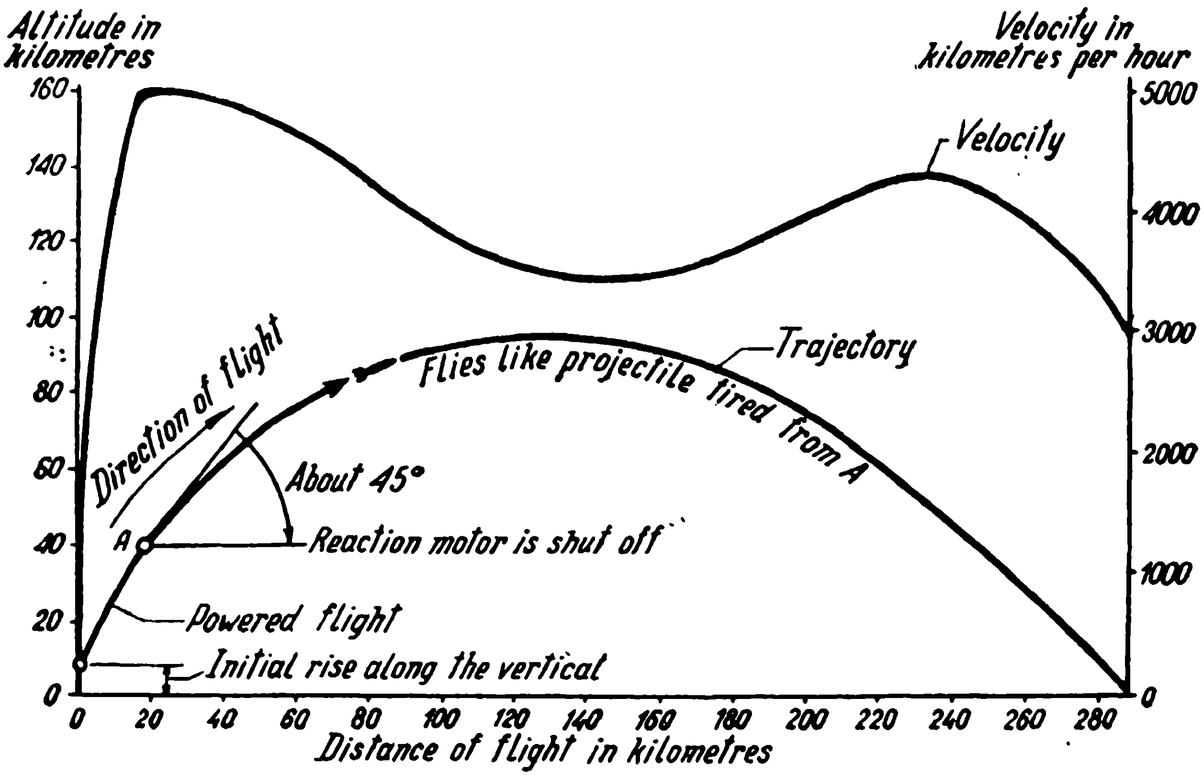
Finally the fuelling is over and the rocket can be launched. The fuel taps are opened, the alcohol and oxygen begin to flow into the combustion chamber of the motor. There the fuel is ignited and the heated gases resulting from the combustion begin to escape through the motor nozzle into the atmosphere at a tremendous speed. The force of reaction of the stream of gases escaping from the motor is directed upwards; it tries to raise the rocket, to force it off the ground.

True, that is no easy matter, for the rocket weighs 13 tons! However, it seems that when working normally the rocket motor can develop a thrust of twice the weight of the rocket—a thrust of 25-26 tons. This is the thrust of modern powerful locomotives that haul heavy trains. And it is with such a tremendous force that the gases escaping from the rocket below, push it upwards. It takes several seconds after being launched for

the motor to develop this full thrust (in the beginning there is a so-called preliminary thrust of 8 tons). Increasing rapidly, the thrust becomes equal to the weight of the rocket and then begins to exceed that weight—the rocket trembles, then slowly, as if against its wish, tears away from the Earth and shoots upward, more and more quickly, very soon vanishing from the eyes of the onlookers.

The entire further flight of this rocket is automatic. It is steered by instruments which are on the rocket itself, in a special instrument compartment in back of the war-head. It is impossible to influence the flight of the rocket after it has taken off. The rocket takes off and then, obedient to the orders of its instruments, flies towards its goal, which is 300 kilometres from its starting place.

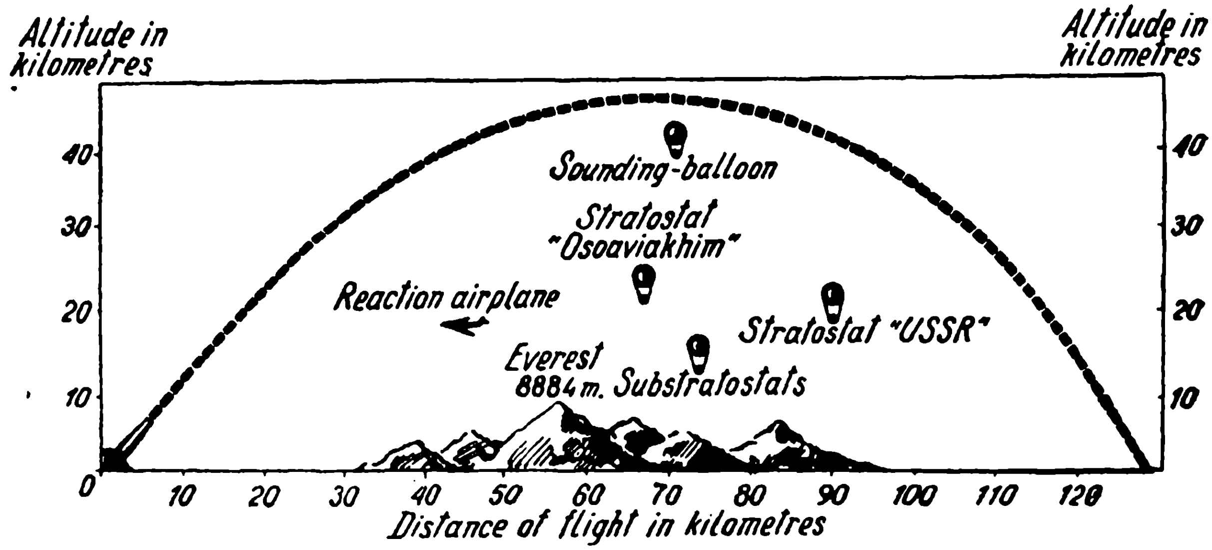
For the first 10-11 seconds after the start the rocket flies straight upwards into the sky. Then the rocket's steering gear deflects its elevators, which are located in the rear. As a result of this the rocket stops rising vertically and begins to fly along a complex curved trajectory, which, by the way, approximates the arc of a circle. Flying in this fashion the rocket attains a very great altitude, about 40 kilometres. At this altitude the rocket motor is turned off and stops operating. By this time it has suc-



Trajectory and velocity of rocket flight.

ceeded in using up all the fuel stored in the rocket, all nine tons. Both gigantic tanks, the alcohol and the oxygen, are practically empty by this time.

How much time has elapsed since the take-off of the rocket? All in all about one minute. During this one solitary minute, the rocket succeeded in attaining an altitude of 40 kilometres, and its motor, in one truly gigantic gulp, swallowed nine tons of fuel.



Trajectory of artillery projectile.

However, the motor does not expend this fuel in vain, for during the flight it develops a truly colossal power.

If we may judge by the energy of the jet from the motor, its power is almost 400,000 horse-power. The useful power that corresponds to the work of moving the rocket in the surrounding medium is even greater. This power increases constantly with the increase in the flight speed, for it is equal to the product of the thrust and the velocity. Before the motor stops, the rocket flies at a velocity of about 5,500 kilometres an hour, or 1.5 kilometres a second. At this time the useful power exceeds half a million horse-power.

After the motor stops working, the rocket continues its flight by using the velocity accumulated earlier, like a projectile that comes flying out of the barrel of an artillery gun. True, in the given instance it would be necessary to place such a gun at an altitude of 40 kilometres. Flying this

way, the rocket goes even higher and reaches a maximum altitude of about 100 kilometres.

But even 100 kilometres is by no means the limit of modern reaction technique, just as the flight speed of 1.5 kilometres a second is not the maximum velocity. By using Tsiolkovsky's ideas, it has already become possible to achieve considerably greater success in the conquest of space by means of reaction technique.

What are these ideas?

Chapter 7

"DWINDLING" PROJECTILES AND "DWINDLING" TRAINS

Since we know what velocity an interplanetary ship must have and since we have found the motor it needs, it should not be difficult to calculate the space ship, to determine the necessary fuel supply, the total weight of the ship, and the trajectory of its flight. However, in his very first attempts to solve the simplest problems, as, for instance, to determine how far any rocket will fly or how high it will rise, Tsiolkovsky came up against a somewhat unexpected difficulty. Prior to him no one had as yet solved such problems. And, as things proved, they were not such simple problems after all.

We know, for instance, that the science of motion, or mechanics, founded by Newton, governs the laws of motion of various bodies. And, naturally enough, Tsiolkovsky, when looking for the solution he needed, turned to mechanics for help. However, at that time this science proved unable to help him.

Before Tsiolkovsky, the science of mechanics had always dealt with bodies that had a definite mass. And that was all well and good, for so far only such cases had been met with in practice. It would be difficult, for instance, to imagine a problem connected with the falling of a stone of any kind, which, during its flight, "became thin," losing part of its mass.

But, alack and alas, Tsiolkovsky was confronted with these very problems. The mass of the rocket changes considerably during its flight, inasmuch as part of it is thrown off in the form of the products of fuel combustion. That is why the rocket, as long as its motor works, is unlike the usual projectile. It is a special sort of projectile, one that rapidly "dwindles" in flight. Just call to mind the rocket described in the preceding chapter.

During but one minute of powered flight, the weight of this rocket decreases from 13 to 4 tons. A catastrophic "dwindling away."

In order to calculate the flight of the rocket, it was first necessary to write a new chapter on mechanics—the mechanics of bodies with a variable mass. Without this it was impossible to formulate the science of the movement of rockets—rocket dynamics.

The honour of having solved these problems belongs to Tsiolkovsky. And in solving them he rendered one of his greatest services to mankind, to science. The laws governing the mechanics of bodies with a variable mass, as developed by Tsiolkovsky, make it possible to solve a number of important technical problems; they form the basis for the theory of interplanetary travel.

It is interesting to note that practically at the same time that Tsiolkovsky worked on this problem, but independently of him, another outstanding Russian scientist, Professor I. Meshchersky, also studied the mechanics of bodies having a variable mass, and solved a number of important problems in this field.

In order to study the laws of motion of a rocket Tsiolkovsky considered the simplest case of rocket flight—its flight in such space where there was no resistance of the air and no force of gravity. Tsiolkovsky called this conditional space "free space." The space ship, during its flight in interstellar space, will be moving under approximately such conditions: there is no air and the force of gravity for the time being can be ignored if the space ship is not in the direct neighbourhood of large heavenly bodies.

The chief task confronting Tsiolkovsky was to determine the final velocity of the rocket, that is, the velocity a rocket will acquire when its motor stops operating because of the consumption of all of its fuel.

Tsiolkovsky was the first to solve this problem, the solution of which he published in 1903. The formula he obtained, which enables one to determine the final velocity of the rocket, is of tremendous importance for the whole study of rocket theory and for the theory of space travel as well. This formula, the so-called rocket formula, is known throughout the world as Tsiolkovsky's law or Tsiolkovsky's formula.

Tsiolkovsky's formula makes it possible to answer a very important question: on what, after all, does the final velocity of a rocket depend? We find that this velocity does not depend on whether the rocket is small or great, nor on the fact that it has a fuel supply of several kilogrammes

or several tons, nor, finally, on the length of time its motor operates. It depends only on two conditions: on the jet velocity and the relative supply of fuel on the rocket, that is, what part of the total weight of the rocket at take-off is the weight of the fuel, the fuel-weight ratio.

The final velocity of the rocket will be all the greater, the greater the jet velocity (the velocity at which the gases escape) and the greater the relative supply of fuel, the fuel-weight ratio.

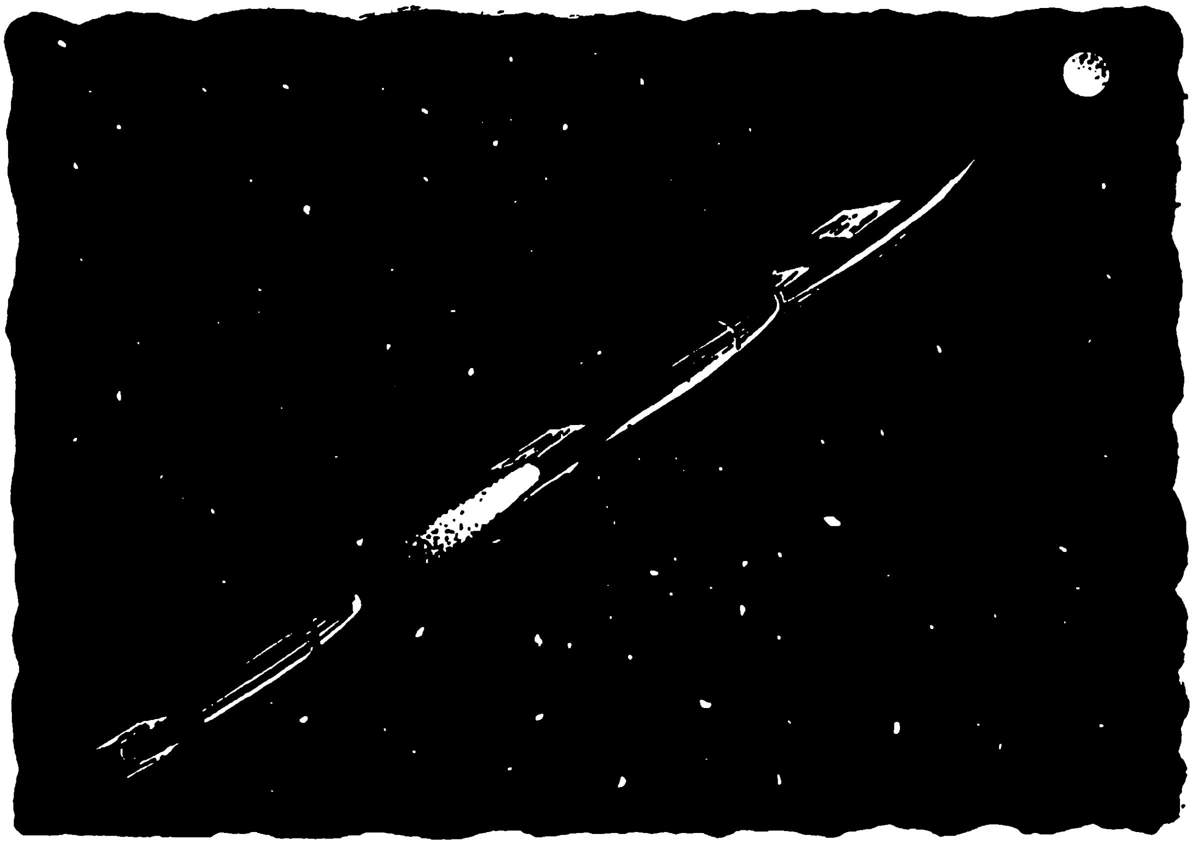
For modern liquid-fuel rocket motors a jet velocity of 2,500 metres per second is considered very good.

What should the fuel-weight ratio be?

For the heavy rocket described in the preceding chapter the fuel weight at take-off is 9 tons, while the total weight of the rocket is 13 tons. It follows, therefore, that in this case the fuel-weight ratio is 9:13 or about 0.7. According to Tsiolkovsky's formula, if the fuel-weight ratio of this rocket were increased from 0.7 to 0.8, the flight speed in free space would be increased by 34 per cent, and a further increase from 0.8 to 0.9 would increase the speed by 43 per cent. If we could build a rocket with a fuel-weight ratio of 0.9, the flight speed of the rocket, according to Tsiolkovsky's formula, would be 5,750 metres per second. In order to attain the escape velocity of about 11 kilometres per second, the weight of the fuel supply on the rocket must be 99 per cent of the take-off weight of the rocket. The weight of the rocket itself, of the motor and the useful load should, in this case, be only 1 per cent of the take-off weight of the rocket.

However, it is practically impossible to build such a rocket. Furthermore, an increase in the fuel-weight ratio of the rocket involves more and more difficulties in construction. A value of 90 per cent for the fuel-weight ratio will probably be the maximum achievable in practice. It is unlikely that the problem of interplanetary flight will be solved by increasing the fuel-weight ratio. The best sorts of fuel that may be created in the future, even if the values for the fuel-weight ratio of the rocket are the greatest possible, will ensure a flight speed of not more than about 9 kilometres per second. This will be the case even if we do not take into consideration various losses.

Yet Tsiolkovsky's remarkable talent as an inventor suggested a brilliant solution to this problem. He was the first to propose the idea of a step-rocket, or, as Tsiolkovsky called it, a "rocket train." According to his idea, those parts of the rocket which become unnecessary during flight, are



Scheme of Tsiolkovsky's "rocket train."

thrown overboard, or jettisoned. Like every outstanding idea, this proposal of Tsiolkovsky's is a combination of exceptional simplicity and remarkable effectiveness. Independently of him and at the same time the American Goddard suggested the same thing.

Tsiolkovsky proposed that the rocket, in this case, should consist of a number of independent, autonomous compartments, that is, a number of separate rockets connected one with another. Just imagine a chain of such rockets, resembling the usual train of railway cars, but set up vertically.

This rocket train should fly as follows: at the take-off the first motor to operate will be that of the very hindmost rocket,* which carries the entire train to a great altitude and imparts a considerable velocity to it. When all the fuel on this rocket is consumed, it automatically separates itself from the train and falls to the earth or descends by parachute. That very

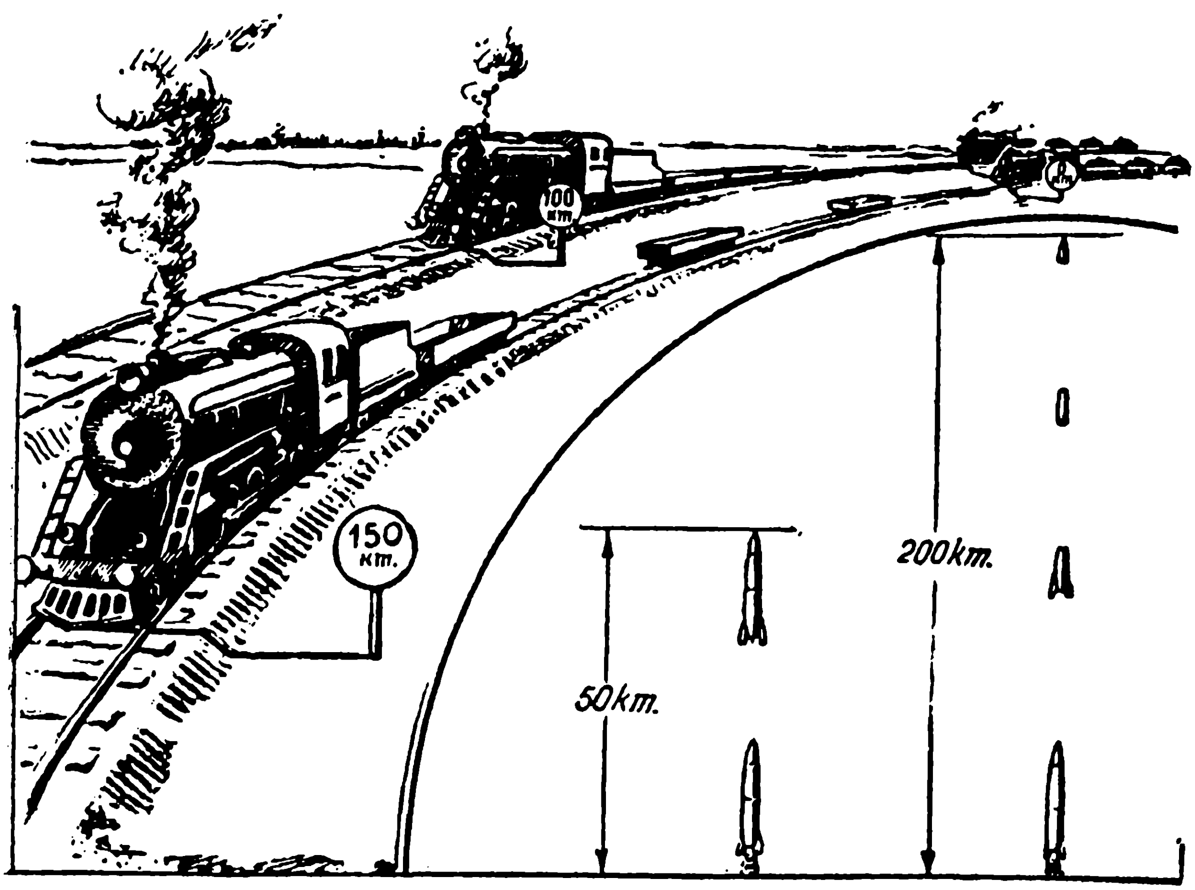
* Tsiolkovsky proposed that the motor of the foremost rocket operate first, so that the train, during flight, would be stretched out by the thrust and not contracted.

same instant the second rocket begins operating and it continues to increase the velocity of the entire train until its fuel supply comes to an end. At that moment it, too, separates from the train. The motor of the next rocket then starts working, etc.

In this respect, this train is quite unique and differs greatly from the usual train. As it gradually dwindles in flight, all the passengers in such a train should be in the first "car," or they risk never reaching their destination.

It is easy to see that the velocity of the very last rocket to operate, that is, the first rocket, will, in this case, be greater than the speed of the entire train would be when expending the same amount of fuel. For in this case it is not necessary to haul a dead load in the form of rockets that have served their purpose and are no longer of any use.

The greater the number of steps in the rocket, the greater the effect obtainable (we can calculate the most advantageous number of steps). For instance, if a rocket with a useful load of five kilogrammes is to acquire



"Dwindling" train: above—railway; below—rocket.

the escape velocity, it may be a five-step rocket and its take-off weight should then be 375 tons. If the number of steps of the rocket is increased to 10, the total weight of the train at take-off will be decreased to less than one-sixth and will amount to only 60 tons.

However, according to Tsiolkovsky, there is little to be gained in building rocket trains with a very large number of steps, besides which, there are serious designing difficulties involved here. It is sufficient to point out, for instance, that a train consisting of five rockets would ensure a velocity five times greater than one rocket, but the useful load in this case would be decreased 10,000 times, and for every ton of weight of the initial step there would be only ... 10 grammes of useful weight!

We can consider that in practice it will hardly be feasible to build rocket trains having more than 5-7 steps. In his work, *Cosmic Rocket Trains*, published in 1929, Tsiolkovsky discusses in detail various possible types of trains.

The idea of building step-rockets, as proposed by Tsiolkovsky, has already found wide application in military rockets. In particular, two-step rockets were widely used during the past war. We may say, in this connection, that with the aid of three-step rockets altitudes and velocities for rocket flights were attained, that are records for modern reaction technique. We shall tell you about them in Chapter 10. More intricate step-rockets were also used, e.g. the military dry-fuel rocket, which had four steps.

F. Tsander, a Soviet engineer, further developed Tsiolkovsky's, idea of multiple rockets. It is obvious that if we were able to use the unnecessary parts of the rocket, those that are later jettisoned, as fuel for the liquid-fuel rocket motor, the final velocity of the rocket would be increased. It is this very idea that forms the essence of Tsander's proposal. He developed a number of designs for interplanetary multi-step rockets in which those metallic parts that become unnecessary in flight, such as the emptied tanks, wings and others, are melted and delivered to the combustion chamber of the liquid-fuel rocket motor. It was Tsander, as we pointed out in the preceding chapter, who suggested using a number of metals, aluminium and others, as fuels for liquid-fuel rocket motors. He also conducted experiments in burning such metallic combustibles.

When developing his study of rocket dynamics, Tsiolkovsky did not confine himself to the simplest case of flight in free space. He considered

many other, very important problems in the theory of interplanetary flight, and developed formulas which form the basis for astronautics. Gradually making his task more intricate, Tsiolkovsky studied the flight of a rocket in the field of gravity. He studied the influence of the resistance of the air, in other words, the flight of a rocket in the Earth's atmosphere, as is the case during the take-off and the landing of a space ship. Tsiolkovsky established the most advantageous methods for the take-off of a space ship and calculated the fuel supply necessary to make various space flights. These and other valuable results obtained by him in his studies of the theory of space travel supplied a stable, theoretical basis for astronautics.

What prospects for the development of reaction technique can astronautics count upon, when making plans for the gradual conquest of the boundless expanses of space?

Chapter 8

FROM THE ROCKET PLANE TO THE COSMIC SHIP

The decades that have elapsed since Tsiolkovsky founded the science of astronautics have shown how correct was his strategic plan for the conquest of space.

Tsiolkovsky considered that the roads leading to space and to the development of aviation and reaction technique coincide. First of all, greater and greater altitudes would be attained by aircraft with the usual piston motors. Then would come the creation of "semi-reaction stratoplanes" (as Tsiolkovsky called planes with air-reaction motors many years before such planes actually appeared) with increasingly greater flight velocities and altitudes. Finally, we come to rocket planes with liquid-fuel rocket motors, capable of flying in the uppermost strata of the atmosphere at speeds other planes are incapable of. And still later, with the gradual increase in flight speed, altitude and distance, and a decrease in the surface of the supporting wings, we arrive at the cosmic rocket.

Many Western scientists viewed the matter differently. They wrote that astronautics would develop independently of aviation, that it would go its own way. According to them, the science of astronautics was quite a new field of endeavour, the creation of a cosmic ship was a task that had to be solved from its very foundation, as something completely new, so that the experience of aviation could be of no help whatever here.

We now can say that history has refuted these assertions. There is no doubt whatever that the entire trend of development of aviation and reaction technique has been such as to prepare the ground for the solution of the problems of astronautics. Without resorting to the experience accumulated throughout all these years by aviation and reaction technique, it would be impossible to construct a cosmic ship. Aviation and reaction technique form the technical foundation for astronautics. It is for this very reason that the possibility of making flights in space becomes more actual with every year, and the age-old dream of mankind—ever more tangible.

The development of reaction technique has revealed another very interesting feature, which, too, had essentially been foretold by Tsiolkovsky. Two branches of reaction technique, which had hitherto been independent of each other—aviation and artillery—are gradually drawing closer to one another. The construction forms of airplanes and rockets are beginning to resemble each other, and we are beginning to divine in them the future outlines of cosmic ships. Planes are gradually losing the shape characteristic of the usual propeller aircraft: the nose of the fuselage is becoming more pointed, as in the projectile; the wings are becoming smaller in dimension and are acquring an arrow-like form; the wing-section is losing the form of an elongated drop of water and is acquiring the shape of a sharp-edged wedge. On the other hand, heavy reaction projectiles are acquiring ailerons and are beginning to look like some of the new jet planes.

The very mechanics of the flight of airplanes in the future may come to differ very much from that of the present and may approach the mechanics of artillery. Today the motor of an airplane, as one knows, works throughout the entire flight, whereas the motor of a reaction projectile operates only for a brief interval, when it is fired, at the start. By installing in the plane a motor with a greater thrust, it will be possible for the plane to fly like a projectile. In this case the motor of the aircraft will work only a short time, during the take-off, when running the plane to a very high velocity and sending it up to a tremendous altitude, the way a projectile does. The plane's further flight will be made with the motor turned off, so that no more fuel is expended, and the plane will make a long free flight, gradually coming down. Calculations show that in this way a plane can fly a much greater distance and make such a flight in

considerably less time than the existing planes of all types are now capable of.

There is no doubt that this is the very way that super-distant and super-speed flights on Earth will be effected in the future. For instance, we will, in this way, be able to fly from Vladivostok to Moscow in about one hour, outstripping the seeming motion of the Sun. So that, after having supped in Vladivostok we will be able, that same day ... to have breakfast in Moscow! Such flights make aviation akin to astronautics, for when making them, the aircraft must fly at what is essentially the threshold of space. The flight technique of a space ship will also be based on a short run in the beginning and a consequent long free flight. In Chapter 10 we shall discuss in greater detail the possibility of such astronautical flights on Earth.

Tsiolkovsky's formula, which we discussed in the previous chapter, shows along what lines reaction technique must develop in order to solve the problems of astronautics. Reaction flying machines must be improved in order that:

a) the machine of a given weight should accommodate as large a weight supply of fuel as possible; b) the liquid-fuel rocket motor should ensure the greatest possible jet velocity.

What are the prospects for the development of reaction technique in these two directions?

The possibilities of further increasing the fuel-weight ratio of the rocket are today very limited. Recall the long-range rocket described in Chapter 6. The weight of the fuel on this rocket was $2^1/_4$ times the weight of the empty rocket. In the best of cases, it may be possible to increase the fuel-weight ratio to $3^1/_2$-4, which would be a remarkable achievement. For the usual light aluminium tank with a capacity of 10 kilogrammes weighs about 1 kilogramme. In other words, as regards the weight of the rocket, for every kilogramme of fuel stored on it, it will weigh only four times more than such a tank. But the rocket is calculated for flight at tremendous speeds, and it must, therefore, withstand great inertia overloads that arise during this flight. Furthermore, there is a motor in the rocket, intricate instruments, steering gear. All of these considerably increase its weight.

Only by using step-rockets, proposed by Tsiolkovsky, can we achieve such a situation that for every kilogramme of rocket weight which the rocket will have after all the fuel is consumed, there will be many tens of

kilogrammes of fuel at the take-off, a condition that is necessary for cosmic flight. And Tsander's idea of using parts of the rocket as fuel may increase this ratio many times more.

This explains why astronautics is interested most of all in that trend of development of jet flying machines, which is closely connected with the perfection of the design of step-rockets, the accumulation of experience in operating them, and the attaining of ever greater altitudes and long-range flights by these rockets, first without people and then with them.

No less intricate and difficult is the task of increasing the jet velocity from a liquid-fuel rocket motor. At the present moment this velocity does not exceed 2,000-2,500 metres per second. An increase in the jet velocity comes very slowly and can be obtained only at the expense of great effort. In order to achieve such an increase, two independent problems must be solved at once: a more highly calorific fuel must be found, that is, a fuel which gives off a greater amount of heat when burning, and the ability of the motor to operate on these fuels must be ensured. The greater the heat given off by the fuel during combustion in the motor, the greater will be the jet velocity, other conditions being equal.

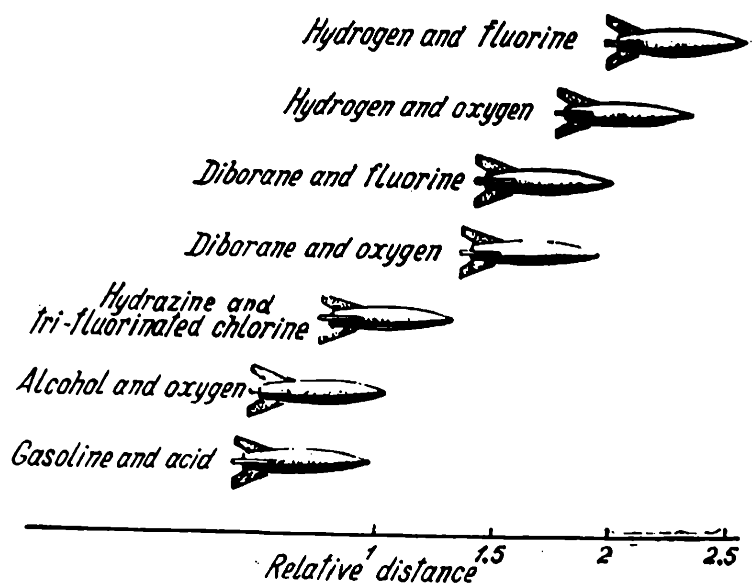
The greatest jet velocities are attained today when liquid oxygen is used as an oxidizer and oil products (gasoline and kerosene) as the combustible. The lowest jet velocity is obtained when hydrogen peroxide or nitric acid is used as the oxidizer.

What are the possibilities of increasing the jet velocity if the best combinations of oxidizers and fuels that can be created with the existing chemical elements are used?

Investigations by Soviet and foreign scientists show that such possibilities are, on the whole, very limited. Such prospective fuels include, for instance, combinations of phosphorus and of silicon, proposed by Kondratyuk, metals and combinations of metals, proposed by Tsander and Kondratyuk, in particular combinations of boron and hydrogen, the so-called "boranes" and others, as combustibles; and as the oxidizers—ozone, proposed by Tsiolkovsky, combinations of fluorine and several others.

A number of new fuels are being studied today. They will, of course, be used in many cases in the future, instead of the fuels of today. However, the jet velocity when such fuels are used will very likely not exceed 4,500 metres per second.

We thus see that chemistry is impotent as regards solving the task of considerably increasing the jet velocity of a liquid-fuel rocket motor, for the chemical energy released when such fuels burn is insufficient for this purpose. However, as yet far from all the resources of chemistry and the possibilities of chemical fuels have been exhausted. Further study in the selection of new, more effective fuels will make it possible to increase the jet velocity, as pointed out above, by about 50 per cent as compared with the value attained today. This would considerably increase the velocity and range of rocket flight, would be a very important step in the development of reaction technique and an important victory in the fight to conquer space.



Relative distance of flight of rockets operating on different fuels. The distance covered by a rocket working on gasoline and nitric acid is taken as the unit.

However, it is not sufficient to find new, more effective fuels if we want to win such a victory. The reliable work of the motor when operating on such fuels must be ensured.

Liquid-fuel rocket motors operate under much more difficult conditions than any other motors, as those of aircraft, automobiles, boats, etc. That is why liquid-fuel rocket motors are less reliable, and the length of operation and the life of the motor are less. These difficult working conditions of liquid-fuel rocket motors are explained by the fact that the working gases in such motors have a high pressure, an unusually high temperature, and move at a colossal speed.

Such working conditions of liquid-fuel rocket motors make the problem of their cooling exceptionally important and difficult. The gases that fill the motor at a pressure of tens of atmospheres and a temperature of 3,000° C. and even more, move against the walls of the motor with a speed that, in many parts of the motor, as in the nozzle, exceeds the speed

of sound. Naturally, a tremendous quantity of heat is imparted to the walls of the motor every second. If this heat is not diverted from the walls of the motor, they will quickly burn through and the motor will immediately stop functioning. There is not a single substance known today, which is capable of withstanding such temperatures at such pressures. That is why a most important condition for the reliability of liquid-fuel rocket motors is a good system of cooling the walls of the motor.

Even today we are unable to use certain high-calory fuels because of the difficulty of cooling the motor. This is due to the fact that when fuels of higher calorific value are used, the temperature of the gases in the combustion chamber is also increased. That is why, for instance, the fuel consisting of loxygen (liquid oxygen) and gasoline or kerosene has not as yet come into wide use. For the same reason, the long-range rocket, described in Chapter 6, operates not on pure alcohol but on alcohol with a 25 per cent admixture of water. This addition of water lowers the temperature of the gases and facilitates cooling, although under such conditions the motor operates less effectively, its thrust being diminished by almost 20 per cent (five tons).

It stands to reason that the use of new fuels of much higher calorific value, such as are necessary for cosmic ships, necessitates a substantial improvement in the cooling system of liquid-fuel rocket motors.

One of these prospective cooling methods is the so-called "penetration" cooling, or "cooling by perspiration," as it is sometimes called. In this case the walls of the liquid-fuel rocket motor are made porous, with a countless number of minute openings having a diameter of thousandths of a millimetre. A special cooling liquid enters the motor via these openings. By this cooling system, the inner surface of the walls which come in contact with the heated gases become completely covered with a thin layer of the coolant, which protects the wall against overheating. The walls seem to "perspire," whence the name for this cooling system. It is possible that the hotter parts of the motors in cosmic ships will have such a cooling system.

Cooling systems for liquid-fuel rocket motors are now being studied most intensively. There is reason to hope that the motors of interplanetary ships will work fully reliably for several minutes or a maximum of several tens of minutes (as far as is now known, that is all that will be re-

quired), and that they will operate on fuels of the future with a higher calorific value.

Inasmuch as the usual chemical fuels do not contain sufficient energy to ensure the jet velocity necessary for cosmic flights, the interest manifested by scientists working in the field of astronautics in other possible sources of energy besides chemical is of course natural. And, needless to say, the problem of using atomic energy comes first.

As is known, atomic, or, to be more exact, nuclear energy is millions of times greater than chemical energy.

The tremendous magnitude of atomic energy makes it theoretically possible to undertake the most distant flights into space. It is sufficient to point out that the energy given off when 20 kilogrammes of uranium or plutonium are split up is sufficient to send a body weighing 1,000 tons to the Moon and back. Authors of books on astronautics usually make note of this circumstance and proceed to paint fantastic projects of such super-distant flights. However, the case here is not so simple as it seems. Atomic energy, although much has been written about it in many books, still does not supply the complete solution of the problem of interplanetary flight.

That an atomic cosmic rocket can be built is no longer a supposition but a fact based on achievements in technique. Such an atomic ship, however, will not differ so greatly in its abilities from the usual ships that use chemical fuel, for the potential possibilities of atomic energy are one thing, the actual technical prospects for using these possibilities—another.

How is this to be explained?

The essence of the matter lies in the problem of how to create an atomic motor with a reaction thrust necessary for the flight of the ship. To obtain this, as we know, we have to throw some substance back at a great velocity. In the liquid-fuel rocket motor the products of combustion of the fuel form this substance. But what will this substance be in an atomic reaction motor? There is nothing in it that burns.

In the atomic motor, instead of the combustion of fuel we have the splitting of the atoms of some nuclear combustible, as the metal of uranium. When this takes place, the complex, heavy uranium atom disintegrates, or, as we say, splits up into two simpler, lighter atoms of other substances. Both of these new atoms, which result from the splitting of the uranium

atom, fly off into opposite directions with a velocity that is equal to tens of thousands of kilometres a second. The kinetic energy of the products resulting from this splitting forms the basic part of the atomic energy given off when the atoms disintegrate.

How can this tremendous energy be used to create the reaction thrust? The simplest thing would be to force the products of this atomic disintegration, which takes place in the motor, to escape from the motor in one direction, through some opening. Then this stream of the substance escaping at a tremendous velocity, which is thousands and tens of thousands of times greater than the usual velocity of the gases escaping from a liquid-fuel rocket motor, would create a correspondingly greater thrust.

However, such a solution, the one that immediately occurs to us, is, unfortunately, impossible in practice.

There are several reasons for this, but one chief reason. If the thrust of such an atomic reaction motor is to be sufficiently great, as is necessary, for instance, when a space ship takes off, a sufficiently large quantity, at least grammes and tens of grammes of the products resulting from the splitting of the atom, must escape from the motor every second. But this means that grammes and tens of grammes of uranium must be split up in the motor every second, from which it follows that the motor must develop colossal power—hundreds of millions and even billions of horse-power. For when a gramme of uranium splits up, as much energy is given off as during the combustion of approximately 1.7 tons of gasoline, that is, every gramme of uranium splitting up in one second is equivalent to about 100 million horse-power.

In such a motor a tremendous quantity of heat will be given off every second. The temperature of the walls of the motor, as a result of the countless number of blows against it caused by the particles whirling about at a tremendous velocity, will reach many millions of degrees, and the motor will evaporate instantly.

That is why a motor designed on this principle is often called a pseudo-rocket. Such a pseudo-rocket could be built only if its thrust were very small; we shall tell you in greater detail about this in Chapter 17.

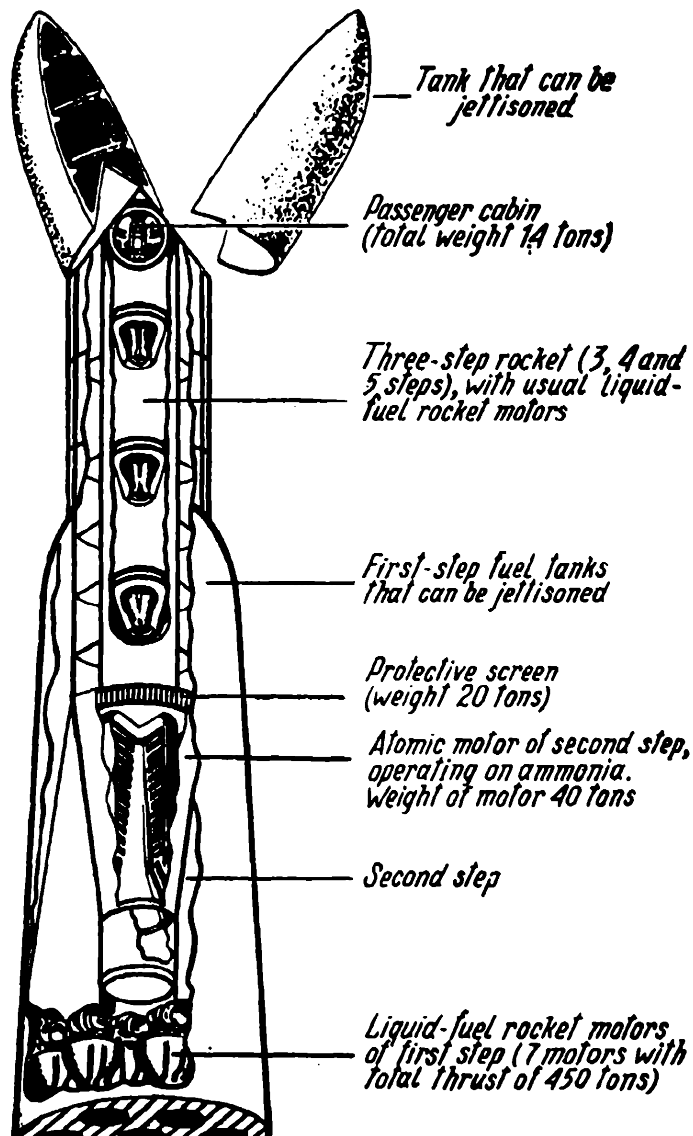
It follows, then, that since the substance which must be thrown off by the atomic reaction motor cannot be the product of atomic disintegration, there must be some other special working substance for this purpose on the ship. Here, indeed, is a substance to be "thrown off." Because

of this, the main advantage of the atomic motor, the practically unlimited duration of its operation, is lost. What, then, is the need of this work if the entire working substance has already been expended? It becomes necessary to stop the motor.

This means that the length of time that the atomic reaction motor of a space ship will work is determined by the possible supply of the working substance on the ship. When, by installing such a motor, we get rid of the supplies of chemical fuel, we, whether we wish it or not, substitute another substance for this fuel. And as a result we arrive at practically the same situation.

The atomic reaction motor will differ from the usual liquid-fuel rocket motor only in that, instead of a combustion chamber, it will have an atomic pile, or reactor, in which the chain process of splitting the uranium atoms or other nuclear combustible takes place. The heat emitted in the reactor will be transmitted to some liquid or gas, the working substance, which will escape as a heated stream from the motor through the nozzle, creating the reaction thrust. In this case the jet velocity may be greater than in the usual liquid-fuel rocket motor.

This constitutes practically all the advantages of the atomic rocket.



Design for interplanetary ship (five-step rocket) with atomic reaction motor in the second step.

The problem of building an atomic reaction motor, which, in theory, can be fully

solved and realized with those technical means that are available today, is, nevertheless, bound with many difficulties that have to be overcome. There is no doubt whatever that this problem will be solved in the future. It will, of course, be a most important victory for astronautics, although, as pointed out above, it will not effect the revolution that so many count upon. Generally, one can consider that the jet velocity of the gases from an atomic motor will be no more than double the maximum possible velocity of gases escaping from the usual chemical liquid-fuel rocket motors. But even in this case the possibilities available to astronautics will increase very greatly, of course.

One of the serious difficulties to be encountered in the building of an atomic interplanetary ship is the necessity of protecting the crew of the ship and the personnel attending its take-off against the harmful effect of the rays which, as is known, are emitted by the operating atomic reactor. If the necessary protective measures are not taken, it will not be possible to come closer to the motor without harm and even without mortal danger, than within several kilometres. For this reason in some designs only one step, the second, of a multi-step space ship is supplied with an atomic motor. In this case, when on the Earth, the atomic motor does not operate, the take-off being effected by means of the usual liquid-fuel rocket motors. When the ship is at a considerable altitude, to which these motors have carried it, the first step is jettisoned, and the atomic motor is switched in. It is then necessary to protect only the ship's crew against the harmful radioactive rays, whereas the land crew no longer needs such protection. A relatively light protective screen can be made, inasmuch as the entire design of the ship, which absorbs the harmful rays, contributes to this protection. After the entire working substance of the atomic motor has been consumed, the second step, the one containing this motor, is also separated and sent down to the Earth by means of a parachute. Further flight is effected with the aid of the usual motors of the other steps, which have a relatively small thrust. Such a ship, to fly around the Moon, will, according to some calculations, weigh 1,200 tons.

Everything we know about reaction technique is evidence that we already have the means of beginning an attack on space.

The third part of this book is devoted to the first results of such an attack and to plans for further attacks.

Part Three

THE ATTACK ON INTERPLANETARY SPACE

> The distance between the wildest fantasy and the most real reality is being reduced with astonishing rapidity.
>
> M. GORKY

Chapter 9

THE ARMOUR OF THE ATMOSPHERE

As a rule, no one stops to think of how much we are indebted to the atmosphere around us for a good deal that takes place in our life.

If there were no atmosphere, life on Earth would be impossible. From the atmosphere we inhale the oxygen without which no living organism can exist. Fortunately, the atmosphere contains a tremendous amount of oxygen, which is constantly being supplemented by the plants. If the oxygen in the atmosphere were liquefied, it would cover the Earth with a continuous layer 2.2 metres thick.

But we need the atmosphere not only because it is a source of oxygen. The atmosphere makes life on Earth exceptionally comfortable. The thick stratum of the Earth's atmosphere protects the life seething on its surface against the direct, harsh influences of the boundless space in which our Earth floats about like an insignificant grain of sand.

The climate that prevails in space is viciously cold. The temperature of a body in space, if it is at a great distance from the stars, as, for instance, the distance of one star from another, is very close to absolute zero, that is, —273° C. Only the heat radiated by distant stars could raise the temperature of this body several degrees above absolute zero. If there were no atmosphere, the temperature of that part of the Earth's surface, which does not face the Sun, would be as low as —160° C., and under the scorching rays of the Sun it would exceed +100° C. Such are the

conditions that exist on the Moon. What would our life be like on such an uncomfortable planet?

The atmosphere, which envelops the Earth like a thick blanket of down, serves as a powerful heat-isolating screen. But the atmosphere is a special, ingenious sort of screen, and you will not find a single blanket of down that can vie with it. For the atmosphere permits the passage of the solar rays, that come rushing to the Earth when the Sun shines, but it will not let the Earth part with the warmth it has received, or disperse it in space after the Sun has set. Thanks to the atmosphere, the Earth's surface is not subject to very sharp drops in temperature, the daily temperature fluctuations being relatively slight. We live on Earth as if within a gigantic thermos bottle of artful design, one that permits the warmth to pass through in one direction, but does not let it pass through in the opposite direction. Indeed, it is terrifying to think what would happen without this "thermos bottle."

Because of the fact that the atmosphere heats up unevenly, air currents and winds arise in it. The energy of these winds has served man from ancient times. These air currents help to regulate the temperature of the atmosphere; they carry the clouds from one place to another and pour benevolent rains upon the ripening wheat fields, creating the circulation of water so necessary to man. The atmosphere is the birthplace of the Earth's climate, with all its specific properties.

But the atmosphere is not merely a thermal screen, nor are the phenomena that take place in it merely heat phenomena. Along with its heat rays the Sun sends down to our Earth an abundance of so-called ultraviolet rays. It is under the action of these rays that our skin acquires that attractive bronze colour we call "sunburn." However, a certain part of these ultraviolet rays, instead of doing good, causes harm. And here, too, the atmosphere steps forward as the invisible champion of all living things: it absorbs the harmful part of the ultraviolet solar beams. If this stream of rays were to reach the Earth's surface with their original strength, life on Earth would very likely be impossible. *

But the Earth's atmosphere protects us not only against the Sun's rays, weakening them, diminishing their strength, filtering and absorbing

* In Chapter 21 we consider, in detail, the effects of various forms of radiation on the human organism.

the harmful beams. Science has established that certain other rays come rushing down to our Earth out of space, from all directions. They are known as cosmic rays.

Cosmic rays are actually streams of particles of matter which consist chiefly of the nuclei of the atoms of hydrogen, helium and several other chemical elements. These particles whirl about at a tremendous velocity. Their energy is millions of times greater than the energy given off when uranium atoms are split up. If not for the Earth's atmosphere, which is the target of this terrible bombardment, it is possible that the unweakened cosmic rays, forcing their way into the human organism, would do great harm.*

However, these invisible, impetuous projectiles do not reach the Earth's surface. They perish in the atmosphere, where they collide with the atoms of the gases comprising it, and disperse all their energy in it. Only the "grandchildren" and "great-grandchildren" of the particles that force their way into the atmosphere, that is, only those fragments of the nuclei of the atoms with which these particles collide in the atmosphere, reach the bottom of the ocean of air. The energy of the particles that reach the Earth's surface and which penetrate not only us but the Earth itself, to a depth of scores and hundreds of metres, is tremendous; but it is, nevertheless, immeasurably less than that of the initial, primary particles. Thanks to the atmosphere, the intensity of the cosmic rays on the Earth's surface is such that they are not dangerous to people.

The Earth's atmosphere not only protects us against the effects of these fatal rays and the bombardment of invisible particles. Space bombards the Earth with even more substantial "projectiles," heavenly stones, meteorites. Many millions of these missiles come flying into the Earth's atmosphere all the time, at a velocity of scores and hundreds of thousands of kilometres per hour, which is many times greater than the velocity of a projectile that comes flying out of the barrel of an artillery gun. True, the dimensions of most of these projectiles are not very great. They resemble minute grains of sand, but their tremendous velocity makes even such grains of sand dangerous. If not for the atmosphere, in which most of

* The question of whether or not these rays would indeed be dangerous to man has not as yet been definitely settled. Some scientists are of the opinion that they would not cause great harm since the total number of these particles in the cosmic rays is relatively small.

these heavenly stones are destroyed and consumed, one such "shower" of stones would make life on Earth impossible or, to say the least, very dangerous.

Without the atmosphere there would be no sound. We would be unable to speak, unable to hear. What an impoverished world this Earth of ours would be!

And what an invaluable service the atmosphere renders in supplying oxygen for countless thermal engines, in furnishing a support for the wings of airplanes, for the propellers of helicopters, for air balloons!

Besides rendering us numerous services and making our life on Earth not only possible but comfortable in many ways, the atmosphere is the source of many remarkably beautiful scenes in nature, which have been extolled by poets of all nations for thousands of years: the blue of the sky, the play of colours at sunrise and sunset, the fantastic forms of the clouds, the twinkling of the stars and the caressing softness of twilight, the inimitable fireworks of the northern lights. For all this beauty we are indebted to the Earth's atmosphere.

The atmosphere is splendid when we consider our life on Earth. But when we make plans to desert our Earth and travel through space, it not only ceases to be of any help, but is even a hindrance. No matter where we direct our space ship, it will have to fly through the Earth's atmosphere, will have to pierce this "armour" and overcome difficulties that are connected with very rapid flight in the air. Even greater difficulties await the ship on its return to the Earth.

To defeat the enemy one must know him. What our Earth's atmosphere really is, how high it extends above the Earth, what dangers lie in wait for the ship on its way through the atmosphere, and how these dangers can be avoided—all these are questions which, naturally enough, interest the designer and the captain of the space ship.

The atmosphere which envelops the Earth extends to a tremendous altitude above it. However, it is impossible to say just where the atmosphere ends and where space begins, at an altitude of 100, 1,000, or 10,000 kilometres. The atmosphere gradually, unnoticeably, changes into space, and it is absolutely impossible to draw any sharp line of demarcation between them.

As the altitude above the Earth increases, the density of the atmosphere decreases, and the number of air molecules per unit of volume becomes

ever less and less. The main mass of atmosphere lies just above the Earth's surface, at low altitudes. If we were to cut out a vertical, endlessly long column of atmosphere, having a cross-secton of 1 sq. cm., the weight of the air in this column would be equal to about 1 kilogramme. And if we were to cut off the lower end of this column to a length of 1 kilometre, the weight of the air in the column would immediately be diminished by 100 grammes, that is, by 10 per cent. The weight of the air in the lower end of such a column 5.5 km. long will be 0.5 kg., or half of the total weight of the air in the column. The lower end of a column 18 km. long would contain $^{14}/_{15}$ of all the air in the column. And if we were to rise up along such a column to an altitude of about 150 km., all the air above us would be equal to only one hundred-millionth part of the total weight of the air in the column, that is, about one-hundredth of a milligramme. All the rest of the air would be beneath us.

We may, therefore, get the impression that there is practically no atmosphere at such altitudes, but even at such an altitude, a cubic centimetre of atmosphere contains about 100,000 million molecules of air. Even at altitudes of thousands of kilometres there are still traces of atmosphere, which is billions of billions of times rarer than at the Earth's surface—at such altitudes there are only several hundreds and perhaps only tens of molecules in a cubic centimetre. Even that which we are accustomed to calling airless space is actually not completely void of matter; individual molecules and atoms float about in it. So we see it is impossible to determine the boundary of the atmosphere on the basis of its density. Such a boundary can only be conditional.

Nor will its other properties help us much to determine the boundaries of the atmosphere.

For instance, suppose we consider the "comfort" qualities of the atmosphere, that is, those qualities which make life livable for people. The boundary of the atmosphere will then be rather close to the Earth's surface. Even at relatively low altitudes a person cannot live outside the hermetic cabin or without wearing a special suit, even if he wears an oxygen mask, for the external pressure will prove insufficient. Experience shows that a trained person loses consciousness in 10-15 seconds at an altitude of 15 km., and that this period does not change when the altitude is further increased. Only the exceptional physical hardiness of Kokkinaki enabled him to reach an altitude of 14.5 km., in his record flight of November 21,

1935. Thus, judged by these properties the atmosphere extends no higher than 10-15 kilometres.

The action of the atmosphere as a filter is manifested at somewhat greater altitudes. At an altitude of 20-25 km. the cosmic rays retain almost their full strength, and the ultraviolet solar rays—at an altitude of over 30-35 kilometres. At an altitude of 100-110 kilometres one can expect serious unpleasantnesses from encounters with meteorites. It is at this altitude that "shooting stars" usually flare up.

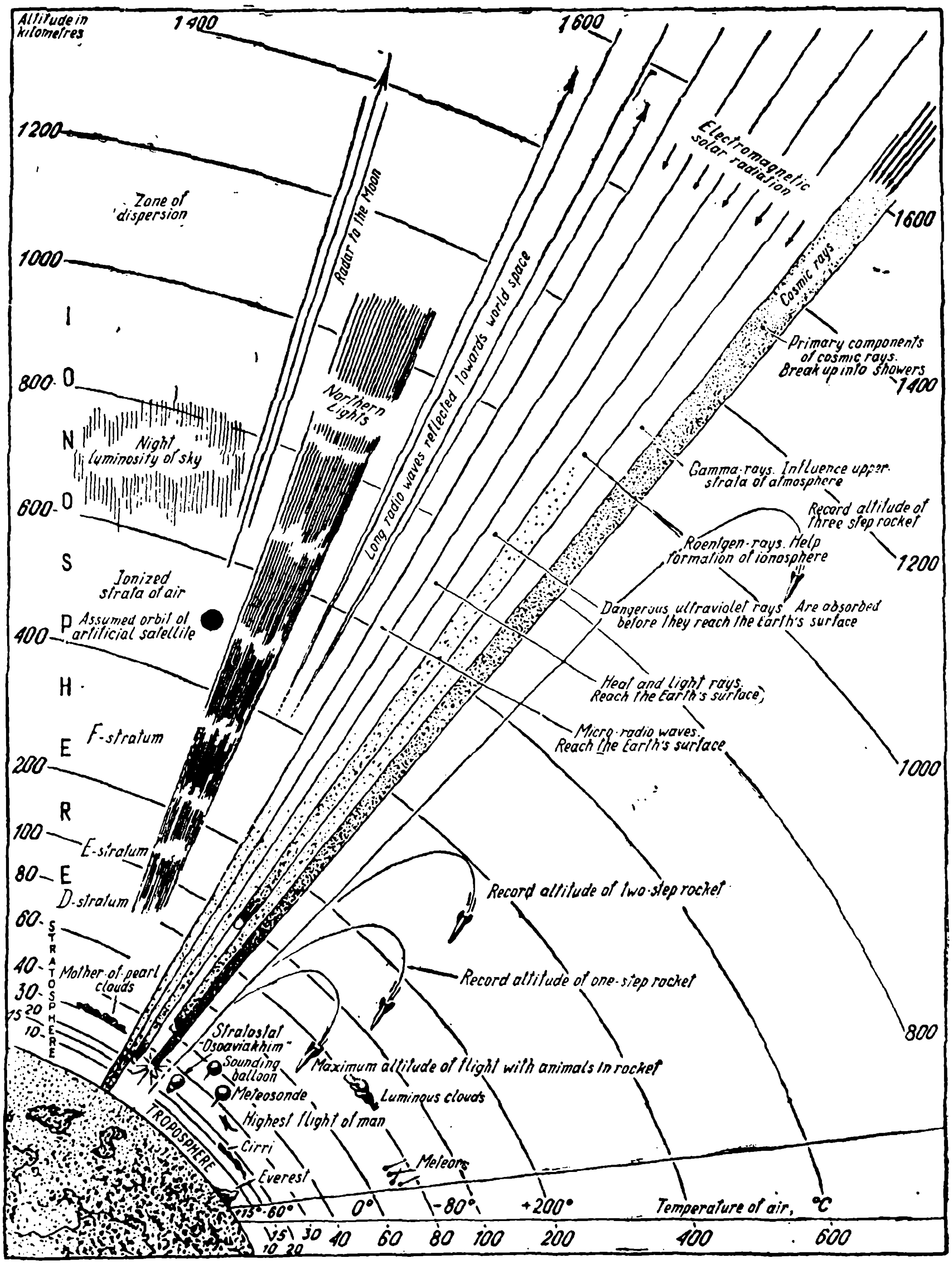
And so, if we base our conclusions on the properties of the atmosphere just mentioned, interplanetary space begins at an altitude of 15-20 kilometres and becomes "absolute" at an altitude of over 100 kilometres. However, there are certain atmospheric phenomena that occur at much higher altitudes, in particular, the northern lights, which sometimes blaze at an altitude of 1,000-1,100 kilometres.

The resistance which the atmosphere offers to any body moving in it at a definite velocity depends on the density of the air. This explains why, when the density becomes insignificantly little at these altitudes, the resistance is exceptionally small. We may assume that this refers to altitudes of about 100 kilometres, but certain scientists consider that during flights at a tremendous cosmic velocity the resistance of the air must not only be taken into account, but it may also play a relatively important role even at altitudes of many hundreds of kilometres.

It is usually considered that the so-called zone of dissipation begins at an altitude of 800-1,000 kilometres. Part of the air molecules vanish from this zone, flying off into space, in which they are scattered. The air in this zone is so rare, that a molecule can fly for many hundreds of kilometres before colliding with another molecule. These collisions rarely occur there, whereas at the Earth's surface molecules collide hundreds of thousands of times along a path of one centimetre.

The structure of the Earth's atmosphere is not uniform, and a space rocket, when traversing the atmosphere, will pass from one zone to another like an alpinist, who passes through various climatic zones when making a high-mountain ascent.

The stratum of atmosphere that lies closest to the Earth's surface, the so-called troposphere, extends to an altitude of 7-18 kilometres, depending on the time of the year and the latitude (less at the poles, greater at the equator). The troposphere is the forge in which the weather is made;



Structure of the Earth's atmosphere.

it is here that most of the processes determining the weather take place; the rains, winds, fogs are born here. The temperature of the air in the troposphere constantly drops as the altitude increases, reaching —50°-60° C. at the upper boundary of the troposphere. This is explained by the fact that the troposphere is warmed by the heat radiated by the Earth's surface. About 80 per cent of all the atmosphere is to be found in the troposphere.

The stratosphere begins just above the troposphere, although one often distinguishes a slight intermediary layer, the tropopause, between them. There was a time when it was considered that the temperature of the air in the stratosphere does not change with the altitude, but remains at about —60° C., and then later gradually drops, so that the cold prevalent in space dominates at the boundaries of the atmosphere. However, a temperature of —60° C. is actually maintained only up to an altitude of 30-40 kilometres, and then the temperature of the air begins to rise suddenly, reaching +60° C.* at an altitude of 50-60 kilometres.

Following this the temperature again drops suddenly: at an altitude of 80 kilometres it is once more below zero; in fact, it is so cold there that even at the pole of cold in the settlement of Oimyakon in Yakutia it is never so cold—80° C. and lower. ** But this is the last drop. Here the temperature of the air once more begins to rise; at an altitude of 200 kilometres it reaches +200°-300° C., while at an altitude of 1,000-1,100 kilometres it is equal to 4,000° C. Some scientists are of the opinion that at even greater altitudes the temperature reaches tens of thousands of degrees.

Not only is this an unexpected phenomenon, but at first glance it even seems a very dangerous one for future space travellers. Will the space ship really have to fly many hundreds of kilometres under conditions similar to those that exist in boilers or open-hearth furnaces, or perhaps even worse? Fortunately, the situation is quite different, and it will not be necessary for the space ship to combat any "fire zone"—the concept

* According to experimental data obtained by means of rockets, the temperature of the air at these altitudes rises only to 0° C.

** It is at this altitude that the so-called "luminous" clouds appear. According to a theory formulated by Soviet scientists in 1951, these clouds consist of minute crystals of ice which form at these altitudes.

of temperature at very high altitudes is different from that on Earth.

The air at such altitudes is so rare that only a relatively small number of molecules will keep hitting up against the surface of the rocket every moment, and it is these very blows that increase the temperature of the rocket envelope. At the same time the rocket's envelope will lose much heat through radiation into the surrounding space. The result is that at such high altitudes there will be no "heat" whatever, and the temperature of the rocket's surface will be even lower than at lesser altitudes, if only this surface is not heated by the solar rays. In this case it may exceed 100° C.

Our knowledge of the upper strata of the atmosphere is constantly being enriched. In this connection the radio-balloons, first flown in the U.S.S.R. in 1930, play no unimportant part. The altitude weather rockets proposed by Tsiolkovsky for this purpose are beginning to play an ever more important role.

There was a time when people thought that there were absolutely no winds in the stratosphere, that a dead calm prevailed there. But such is not the case. There are winds in the stratosphere that blow at a velocity of 300, 400, and—at high altitudes—even 1,500 kilometres an hour. These winds, which are incapable even of stirring a hair on one's head, as the air is so rare there, are remarkable for their constancy; they almost always blow towards the east. It was also formerly thought that the stratosphere in no way influences the climate on Earth, but this, too, has proved to be a mistaken conception.

The stratosphere extends to an altitude of about 80 kilometres, and contains almost all of the remaining air, that is—20 per cent. All the atmosphere that lies above the stratosphere and extends for many hundreds of kilometres upwards, contains less than 0.5 per cent of the total amount of air in the atmosphere.

The fact that the first half of the stratosphere contains a large quantity of ozone* plays quite a special, exceptionally important role in our life. The ozone molecules, which consist of three atoms of oxygen, absorb

* This saving stratum of ozone, which extends for a distance of 60 kilometres upwards from the Earth's surface, would, at sea level, be only about 2-3 mm. thick; 60 per cent of all the ozone is to be found at altitudes of from 16 to 32 kilometres, but its maximum concentration is at an altitude of about 25 kilometres.

the short-wave (so-called hard) ultraviolet rays of the Sun. This stratum of ozone is a filter that protects us against the dangerous unweakened solar rays.

At high altitudes, beginning approximately at 80 kilometres, the atmosphere consists chiefly not of the usual air molecules, but of ions, that is, of molecules and atoms that have an electric charge. This is electrified air. That is why the upper strata of the atmosphere are usually called the ionosphere. The ions appear at these altitudes chiefly as a result of the action of the ultraviolet rays of the Sun, which tear the electrons away from the usual air molecules. This action of the ultraviolet rays explains the rise in temperature of the air as the altitude increases, and also the fact that at very great altitudes there are no longer any molecules of oxygen and nitrogen, which have split up into atoms. The terrestrial atmosphere is, in fact, a tremendous electro-chemical plant, with complex processes taking place in its shops, processes of the formation of various substances with the aid of solar energy.

The strata of the ionosphere, which are located at different altitudes, have different properties, in particular, electro-magnetic, and they therefore influence the propagation of radio waves in various ways. The role of the ionosphere, in this respect, is, we may say, exceptionally great. If not for this electrically charged stratum of the atmosphere, long-range radio broadcasting would be impossible. It is possible only because the so-called D-stratum of the ionosphere, which is at an altitude of 60-80 kilometres, reflects the long radio waves; the E-stratum, located at an altitude of 100-120 kilometres—the medium waves; and the F-stratum, which is to be found at an altitude of 200-300 kilometres—the short waves. These strata of the ionosphere differ in their composition and degree of ionization. That is why they influence the propagation of radio waves in different ways. Waves of the ultra-short wave band, varying from about one centimetre to 15-20 metres in length, to a considerable degree pass through the ionosphere. This will make it possible, in the future, to establish radio connection between the Earth and ships flying in space, but prevents long-distance radio broadcasting on these waves and, in particular, television broadcasts over great distances.

The existence of the terrestrial atmosphere complicates the problem of interplanetary flight. This difficulty is due chiefly to the resistance the air offers a body moving about in it. Because of this resistance it will be nec-

essary to spend more energy on an interplanetary flight than will be required to impart the necessary escape velocity to the space ship. In other words, it will be necessary to impart to the ship an additional velocity, depending on the flight velocity of the ship in the atmosphere—the less it is, the less will this velocity be—and also on the form of the ship and its trajectory. We can assume that the value of this additional velocity will not exceed one kilometre per second, that is, about 10 per cent of the escape velocity.

The atmosphere will occasion the ship serious unpleasantnesses as a result of the fact that the latter will become heated when flying in the air at a great velocity. Neither the designer nor the captain of the ship should overlook this danger for even a moment, as it may prove fatal.

While it is true that in some ways the atmosphere hampers the space ship, it can also render good service if we only make wise use of its properties.

For instance, when the ship lands on Earth, its velocity is reduced by the resistance of the atmosphere without the need of expending any fuel for this purpose, and during a take-off the atmosphere can be of great service to air-reaction motors, which use up less fuel than rocket motors do.

In any case, we already know enough about the Earth's atmosphere not only to send a space ship calmly and confidently through the atmosphere to a distant goal, but even to make best use of the atmosphere's properties for interplanetary communication.

Chapter 10

AT THE THRESHOLD OF SPACE

When dreaming of the conquest of space by man, and when drawing up plans for this conquest, Tsiolkovsky outlined the gradual stages for the solution of this unprecedented task. He realized that the only way to attempt an attack on space was to perfect reaction technique, increase our knowledge of space, and broaden the scientific and experimental foundation of astronautics. First, higher and higher flights in the atmosphere; secondly, leaps beyond the atmosphere, to the threshold of space; then, a more profound exploration of space, flights around the Moon, landings on the Moon; finally, flights around the planets, landings on

them, and the gradual conquest of all space. These are the obvious landmarks on the road leading to the realization of man's age-old dream.

Half a century has elapsed since Tsiolkovsky first outlined his plan to conquer space. But these decades have not been in vain. Tsiolkovsky himself witnessed only the first timid steps along the path he had outlined, the first theoretical work in astronautics, the first attempts of enthusiasts to build liquid-fuel rocket motors, and the first flights of these rockets. After Tsiolkovsky's death, especially during the past decade, reaction technique, which is the technical basis for astronautics, began to develop at a rapid pace. This made it possible to achieve significant results as regards increasing velocities and to undertake that attack on space, which Tsiolkovsky dreamed of.

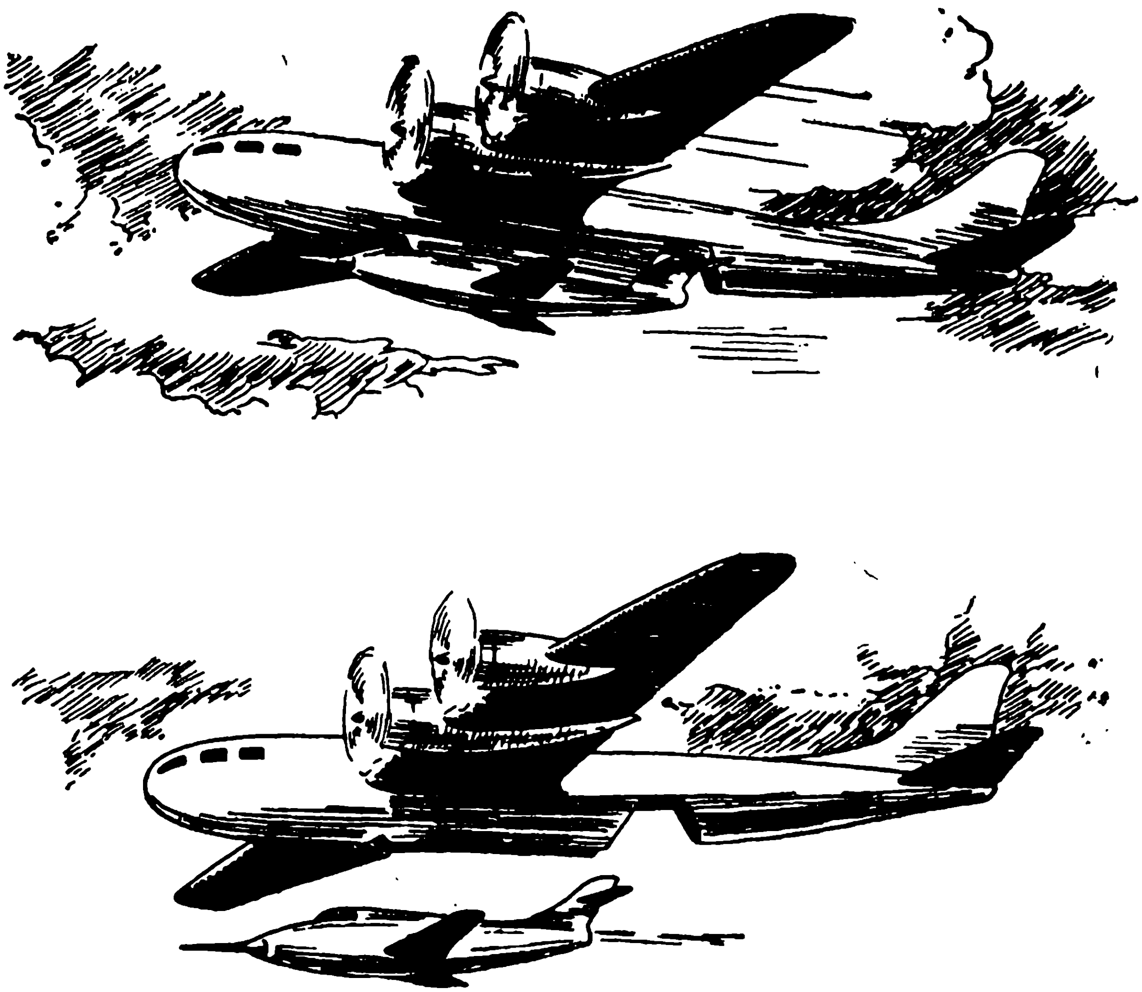
How has reaction technique contributed to the realization of this attack?

Modern jet-propelled planes fly freely in the stratosphere. The official world altitude record was set in 1955 at 20,094 metres, by a jet-propelled airplane with two turbo-jet motors. A turbo-jet motor was also installed in the plane that made a record speed flight in 1956—1,822 kilometres per hour.

Does this mean that there have been no other achievements in aviation since then? By no means! There is every reason to assume that these records have been surpassed by the latest jet-propelled aircraft. It is probably no exaggeration to say that the latest jet-propelled aircraft, with their new, powerful, perfected turbo-jet motors, now fly at velocities far exceeding the velocity of sound.

Even greater altitudes and flight velocities have been attained with the aid of experimental rocket planes using liquid-fuel rocket motors. Inasmuch as the fuel supply on such planes permits a flight of only a few minutes (liquid-fuel rocket motors consume a very great amount of fuel), these planes are often raised to a high altitude by means of heavy "carrier" airplanes. The light, small rocket plane is usually suspended under such a "carrier" and released only at a high altitude, when it begins its independent flight. The fuel which would necessarily be consumed during the take-off and when flying upwards is thus economized.

Such altitudes and velocities have been attained during flights of this kind, as are very likely records for flight by man. According to certain data, a flight speed of 3,500 kilometres per hour and an altitude of about



Rocket plane suspended under "carrier" plane. At a great altitude it is uncoupled and begins its independent flight.

thirty-eight kilometres have already been reached. In these cases the pilots flew under conditions closely resembling flight in space. Of course, the cabins of these planes, as those on other high-altitude planes, including passenger aircraft, are hermetic. This means that the cabins are absolutely isolated from the surrounding atmosphere, the pressure maintained in them is like that of the atmosphere at sea-level, and the air in the cabin is conditioned, that is, there are means to supply the crew with oxygen and to remove the products that are exhaled. In other words, the pilots of such aircraft live under conditions that are very much like those during flight in a space ship.

However, the achievements of reaction aviation are by no means the only ones attained by modern technique in its attack on space.

Reaction technique has made it possible to fly (true, as yet without man) at such speeds and altitudes that far exceed the records set by rocket planes. These flights have been made with the help of heavy rockets that are guided during flight and are supplied with liquid-fuel rocket motors. Some of these rockets have reached altitudes of hundreds of kilometres, that is, they have, we can say, made leaps beyond the atmosphere, have been at the very threshold of space. Tsiolkovsky's dream is beginning to come true!

Rockets used during the past war as super-long-range projectiles had already attained altitudes of about 100 kilometres and flight speeds of 5,500 kilometres per hour. After the war was over, similar rockets were used to make altitude flights for various research purposes, most often in the field of meteorology, their observations being of interest to the weather bureau and for a study of the atmosphere. Tsiolkovsky had also proposed using rockets for this purpose.

It is not surprising that rockets flew to even greater altitudes during such flights. For in these cases the rocket flies only vertically, and does not take any explosive along. Furthermore, as time went on, both the rockets and their motors were constantly being perfected. These stratospheric or, as they are sometimes called, meteorological rockets attained altitudes of 150, 200 and even 250 kilometres, that is, they made their way high up into the ionosphere.

Equipment installed in such rockets to make measurements during flight has made it possible to obtain much new scientific data of the most diverse nature, including such as is of exceptional value. Indeed, as yet this is the only means by which the scientist can fly his instruments to such a tremendous altitude, an altitude that is beyond the limits of the atmosphere, in the direct neighbourhood of interplanetary space.

Of great interest are photographs of the Earth, taken from a high altitude by cameras installed in altitude rockets. Some photos have been made at altitudes over 200 km. Of course in these photos the Earth does not resemble the Earth as we see it not only from the window of a railway car, but even from a plane that flies at a high altitude. Although in these pictures we cannot see any details of the Earth's surface whatever, they are interesting in other respects. It is sufficient to say that these pictures cover a territory 5,000 km. in extent, a fact that affords new possibilities for cartography, for studying the movement of the clouds, etc. It

is also interesting to note that in these pictures we can clearly see the spherical shape of the Earth.

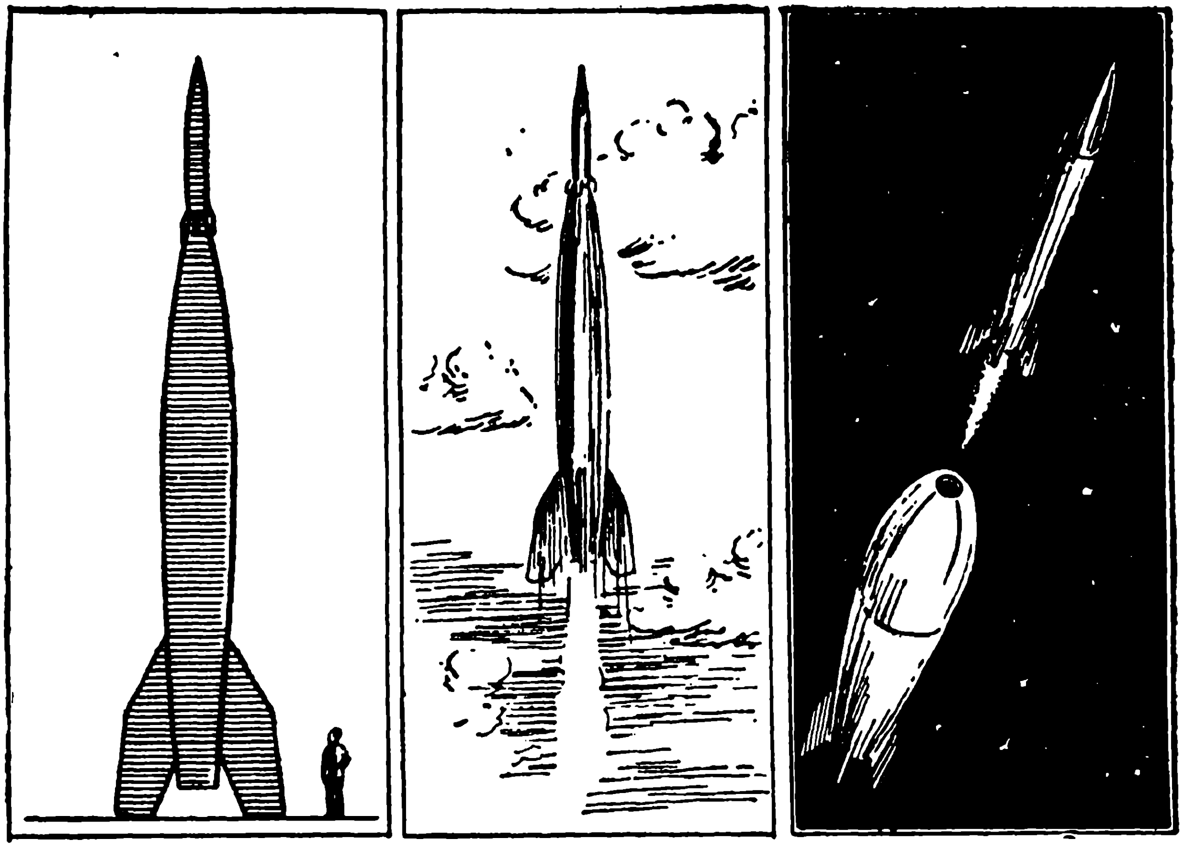
It is Tsiolkovsky's idea of step-rockets or "rocket trains" that has made such flight speed and altitude records by modern reaction technique possible.

At first two-step rockets were used for such record flights. The first or rear rocket is approximately the heavy rocket described above, in Chapter 6. The foremost rocket (which is smaller) was installed on it in the place of the war-head, and weighed about half a ton. When the motor of the rear rocket stopped operating because of the consumption of all its fuel, it separated from the foremost rocket. That very same moment the motor of the foremost, smaller, rocket started operating and the rocket continued its vertical flight. It stands to reason that this front rocket flew higher and acquired greater velocity than one big rear rocket. During one such flight, we are told, an altitude of about 400 kilometres* and a flight speed of about 8,300 kilometres per hour, or about 2.3 kilometres per second, were attained. Quite recently, on November 28, 1956, an even greater altitude, about 1,130 km., was attained by means of a three-stage rocket, fired in the U.S.A., and a flight velocity of about 11,000 km. per hour was attained by a four-stage rocket.

This already marks the conquest of one of the front lines in the attack on space. What now remains to be done is to go beyond the threshold of space and farther into it, ever farther from the Earth and closer to the distant goals of cosmic flights.

The achievements in the development of heavy high-altitude rockets unfold quite new opportunities for super-speed long-range flights on Earth. For this purpose the initial rocket velocity must be considerably increased. Having taken off at such a speed, the rocket can make its way beyond the limits of the dense atmosphere and, flying there at a great speed, can cover tremendous distances. If the initial rocket velocity (at the moment the motor is shut off) is equal to about 5 kilometres per second, the rocket can

* It is interesting to note that at this altitude the decrease in the force of the Earth's attraction is already strongly felt—the weight here is about 10 per cent less than at the Earth's surface. Although 400 kilometres is only 0.1 per cent of the distance to the Moon, the rocket which has attained such an altitude has accomplished about six per cent of all the work necessary for a flight to the Moon—so great is the effect of the decrease in the force of gravity at such an altitude.



Two-step rocket. Extreme right: separation of the upper rocket.

fly about 3,000 kilometres in 14-15 minutes and, while doing so, will have climbed to an altitude of 800 kilometres. Even better results can be obtained if the rockets are equipped with wings.

The idea of winged rockets also originated in Russia. Tsander was the first to propose it. He suggested equipping the rocket with wings whose lift could be used both at the take-off and during the landing of the cosmic ship.

By simply adding wings to the rocket described in Chapter 6, its flight range can be substantially increased. That rocket flew a distance of about 300 kilometres and its flight lasted approximately 5 minutes. The same rocket with wings would make a flight three times as long, or 15 minutes, and would fly almost twice as far, a distance of 550-600 kilometres. Such is the important role of the wing lift.

If we were to combine Tsander's idea of a winged rocket with Tsiolkovsky's idea of a rocket train, the results obtained might truly be wonderful. Just imagine such a rocket train in its simplest form consisting of

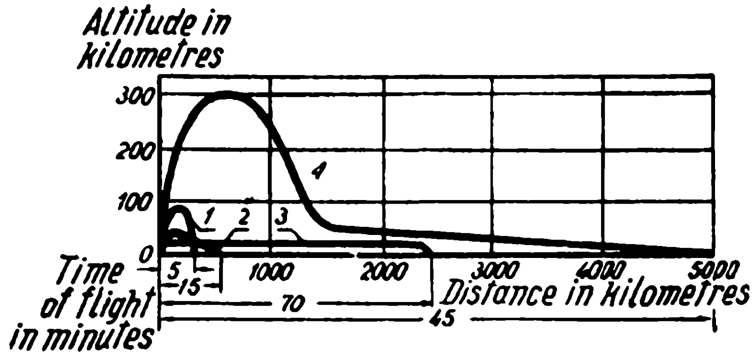
two rockets: the rear one—the usual wingless rocket, and the front one—a winged rocket. Whereas the front step is the one we already know, the long-range rocket but with wings, the rear wingless rocket must be much larger in dimension and its motor must, naturally, possess greater thrust. According to one such project, the thrust of the rear rocket should be approximately 180 tons, the total weight of the train at take-off—almost 100 tons (of which about $^2/_3$ is the weight of the fuel), and the length of the train—over 30 metres.

The nature of the flight of this train will depend upon its aim. At first the rear rocket will lift the entire train to an altitude of about 25 kilometres, at which point the motor of this rocket stops operating because of the consumption of all its fuel; the rocket automatically separates from the train, dropping to the Earth by means of a parachute. The second rocket can now fly horizontally at this constant altitude at a velocity of 2,600 kilometres per hour, until all its fuel is consumed. In this case the total duration of the flight will be about 70 minutes, during which time the rocket will cover a distance of about 2,500 kilometres.

But it is also possible to increase the distance of this flight considerably, and at the same time decrease its duration. Much further and ... much quicker! This sounds paradoxical, but it is strict, scientific calculation based on the remarkable properties of the wings and the properties of the Earth's atmosphere. If, after the rear rocket separates from the train, the front rocket continues to fly vertically, it can attain an altitude of about 300 kilometres, and then coast downward, using the wing lift. The total distance of such a flight will be about 5,000 kilometres and its duration only 45 minutes. The flight speed here will be greater than that ever before achieved by man—up to 12,000 kilometres an hour ($3^1/_3$ kilometres per second).

Studies by Soviet scientists show that by combining tremendous flight speed with wing lift it is possible to make a much more effective flight. The present level of development of reaction technique already makes it possible, in theory, to build a super-long-range rocket plane capable of making a non-stop round-the-world flight.

The creation of a super-long-range plane is possible only because the liquid-fuel rocket motor can ensure tremendous altitude and flight speed. Such a motor works only a few minutes, during which it consumes all the fuel stored up on the plane. And, of course, during these few minutes of

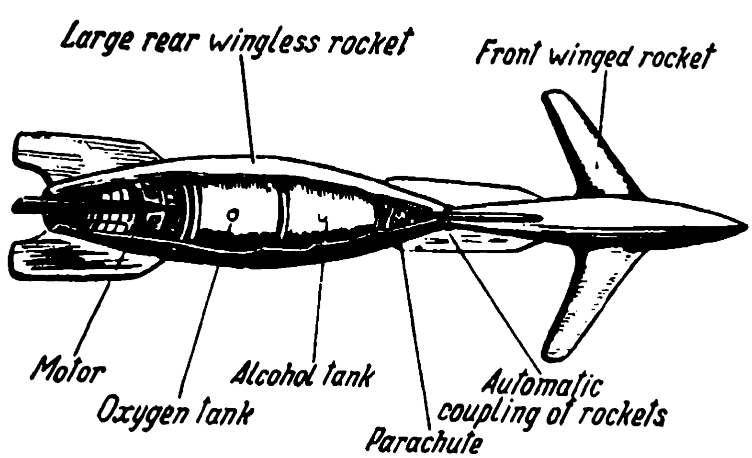


Trajectory of flight of various long-range rockets: 1—initial long-range rocket described in Chapter 6; 2—the same rocket equipped with wings; 3, 4—step-rocket.

powered flight the plane cannot make a long-range flight. But a powerful liquid-fuel rocket motor will, in the very few minutes that it operates, carry the plane to a tremendous altitude and impart to it a tremendous velocity. The free flight of the plane beginning from this altitude can cover a very great distance and be of long duration.

The round-the-world flight of a plane with a liquid-fuel rocket motor will be something as follows: the powerful motor of this plane will, during the few minutes it operates, carry the plane to an altitude of 300-400 kilometres and impart to it a velocity of not less than four kilometres a second, or about 14,000 kilometres an hour. True, to attain such figures, the motor must operate on new and better fuels, such as ensure greater jet velocity than at the present time.

The motor operates only during these first minutes of flight; then it stops and not a drop of fuel is consumed any more. The plane flies forward, expending the kinetic energy it accumulated during the take-off run. In this respect such a flight greatly resembles a flight in space.

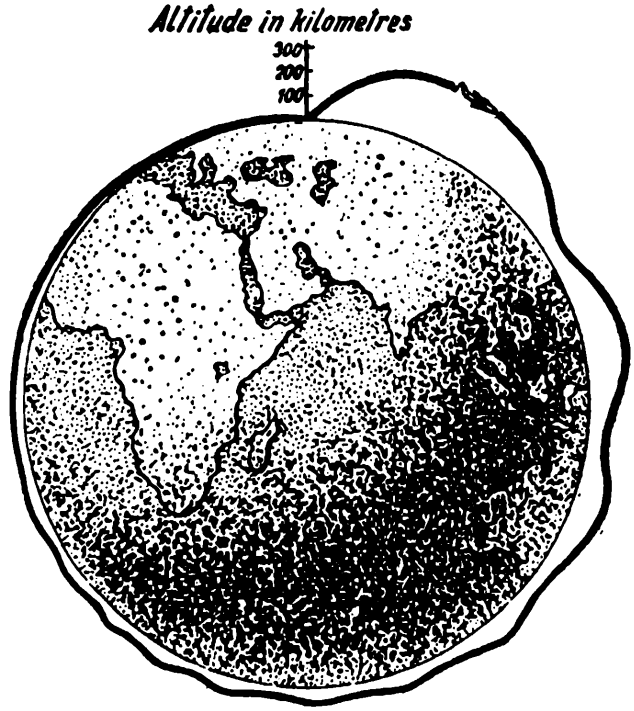


Step-rocket (project).

The plane begins its free flight around the Earth from this tremendous altitude, gradually descending. At first glance it seems that such a free flight at such high altitudes is out of the question, for when gliding, the weight of the plane must be only slightly more than the lift of its wings, and at an altitude

of hundreds of kilometres there is practically no wing lift simply because there is almost no air there. This means that the plane will not come down gradually but will drop like a stone from the altitude to which the motor has carried it.

True, the plane will drop like a stone. And it would, of course, drop very quickly were it not for the fact that it is mobile. But when falling to the Earth the plane is also flying around the Earth at a tremendous speed. If the Earth were flat the plane would soon fall down on it. But it is a sphere so that as the plane continues to drop towards the Earth, flying around it at a tremendous velocity, it succeeds in covering a great distance—6,000-7,000 kilometres. But more than that: when the plane, descending in this manner, breaks into the lower, denser strata of the atmosphere at a tremendous velocity, its wing lift makes itself felt. The plane seems to be repulsed from these dense strata of the atmosphere, it rebounds like a flat stone along the surface of water, and then rushes upwards once more. It will not, of course, attain its former altitude since the velocity has already been diminished, but it can again climb up to an altitude of 200 and more kilometres.



Scheme of round-the-world non-stop airplane flight with liquid-fuel rocket motor.

By going through such wave-like motions, which gradually die down, and by means of its final free inclined flight in the dense strata of the atmosphere, the plane, calculations show, is capable of landing at the very same aerodrome from which it took off. The entire round-the-world flight will take no more than several hours, and the plane will not even have to turn around to land against the wind, as is usually the case, but will land in the very same direction as it took off.

It is not a far step from a round-the-world flight to the creation of the Earth's artificial satellite, but more of this in the next chapter.

Chapter 11

ISLANDS AT THE TERRESTRIAL SHORES

And so, a plane having a velocity of four kilometres per second is able to fly around the Earth and make a landing at the very same aerodrome from which it took off. It goes without saying that if its velocity is greater, it will be able to fly even farther, past its own aerodrome. It may even fly around the Earth twice, three times.

Isn't it possible to make the plane revolve around the Earth a countless number of times? The Moon revolves around the Earth in exactly that way, doesn't it? And the Earth around the Sun?

Of course it is possible, but there are certain conditions that must be satisfied.

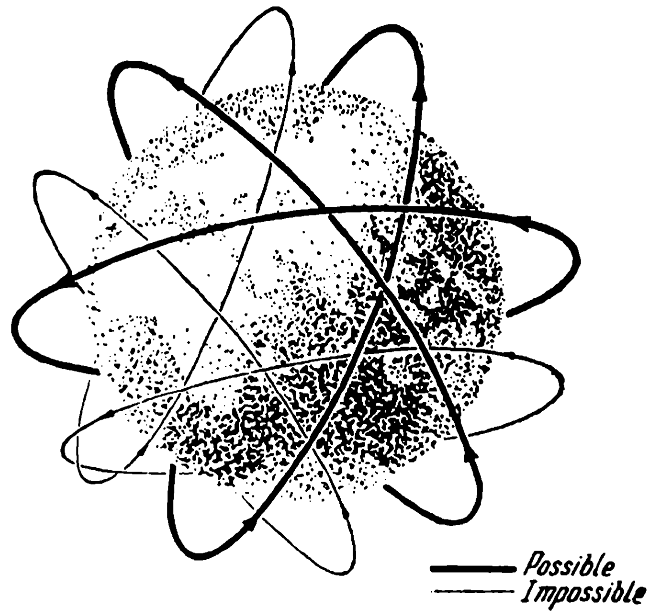
In the first place, such a plane must fly around the Earth at a very high altitude, so that the air resistance will be practically negligible and will not retard the flight speed. Otherwise the motor of the plane will have to work all the time in order to recover that velocity. This, of course, is impossible, for the motor of the plane should not operate during such a flight, except during the take-off run, otherwise the flight will end very quickly as all the fuel stored up on the plane will soon be consumed. If the Moon made its flight around the Earth in the atmosphere, we would probably have been deprived of the charm of moonlit nights long ago, and the Earth itself would probably have long ceased to exist as a result of the catastrophe which must necessarily have ensued, as the Moon would inevitably have fallen down on the Earth.

Of course, the ideal thing would be a flight in space at a distance of thousands and tens of thousands of kilometres from the Earth. However, there is no need to penetrate space to such a depth. Flight becomes fully possible even at much lower altitudes. The trajectory of the flight in the upper strata of the atmosphere will, of course, not be circular, but will be spiral in form, with a gradual lowering because of the air's resistance, but this lowering will be slight—the greater the flight altitude, the less it will be.

For practical purposes we can assume that a plane flying around the Earth at an altitude of about 200 km. will describe an almost perfect circle. It may, perhaps, be necessary for the pilot from time to time, once in several days, to turn on his motor for a brief period to recover his

altitude. And so, the first condition is a flight altitude of not less than 200 kilometres.

The second obvious condition is a sufficient flight velocity. It is easy to see that this velocity must be a very definite one. If it is decreased, the plane will begin to lose altitude; if it is increased, it will fly farther away from the Earth. What is this so-called circular* velocity equal to, at which the flight altitude of the plane above the Earth will remain constant?



Artificial satellite can rotate around the Earth only in the plane of a large circle.

The circular velocity, we find, will be about 7.9 kilometres per second. This is the velocity at which the plane must fly if it is to revolve about the Earth infinitely long in a free flight, the plane having become an artificial satellite of the Earth.

And so, at a velocity of 7.9 kilometres per second the plane will become a satellite of the Earth. If the escape velocity is 11.2 kilometres per second it will leave the Earth for ever. What happens to the plane if its velocity is greater than the circular but less than the escape velocity, as, for instance, 9 or 10 kilometres per second? At such a velocity the plane will also become a satellite of the Earth and will revolve endlessly about it. However, its revolutions will not be along a circular orbit, but an elliptical one, and the nearer the plane's velocity approaches the escape velocity, the more elongated will the ellipse be.

Finally, there is another, a third condition, if the plane is to become a satellite of the Earth. Such aircraft must make its flight in the plane of the great circle, that is, in one of the planes that pass through the centre of the Earth's sphere.

It is clear that the higher the plane flies above the Earth, the less should be the circular velocity at which it flies, for when flying in this

* It is sometimes also called circulation or first cosmic velocity.

way it keeps falling towards the Earth more and more slowly. If the plane flew at such a distance from the Earth as the distance of the Moon from the Earth, its velocity would be equal to the velocity of the Moon's motion around the Earth, that is, about one kilometre per second.*

It is easy to calculate how much time it will take a plane, flying at a circular velocity, to make one revolution around the Earth, i. e., what the period of revolution of this new terrestrial satellite will be.

Thus, for instance, during a flight at the very surface of the Earth, the period of the plane's revolution will be 5,050 seconds, or 1 hour 24 minutes. Less than $1^1/_2$ hours to go around the world!

As the flight altitude increases, the period of its revolution will increase. At an altitude equal to the Earth's radius, that is, 6,378 kilometres, the period of revolution will be equal to about 14,200 seconds or almost four hours.

Of great interest will be such a flight altitude at which the period of revolution of the plane around the Earth will be exactly 24 hours, that is, the same as the period of one rotation of the Earth on its axis. It is easy to determine what this altitude will be—5.64 times the Earth's radius, or about 35,900 kilometres. If the aircraft will speed around the Earth at such an altitude in the plane of the equator and in the same direction in which the Earth rotates, that is, from west to east, at a velocity equal to the circular velocity at this altitude (about 3,070 metres per second), the airplane will seem immobile, as if suspended above one and the same point of the Earth's surface. Such an airplane will resemble a helicopter that hovers motionless above the Earth although it will, at the same time, whirl around it at a dizzy pace.

Of interest is a certain specific feature of such an orbit whose radius is 58,000 kilometres less than the orbit of the Moon, which is equal, as we know, to about 380,000 kilometres. A satellite that revolves along such an orbit will always be situated on a straight line connecting the centres of the Earth and the Moon; it will invariably be seen against the background of the lunar disc.

* To be more exact, the airplane's velocity would be less than the Moon's velocity, for the Moon has an immeasurably greater mass (this follows from Kepler's third law in its more precise formulation).

Tsiolkovsky was the first person to realize how tremendously important the Earth's artificial satellites would be in solving the problem of space travel and for many other scientific studies. It is now generally recognized throughout the world, that the creation of artificial satellites of the Earth will be one of the most important steps in the attempt to conquer space.

According to Tsiolkovsky, after the first successful flights of cosmic rockets had been made along circular orbits around the Earth, at first without people and then with people, and after many questions connected with the realization of such flights had been clarified, it would be necessary to begin building a permanent satellite of great dimensions, an entire island off the shores of the Earth. This island should have a considerable population: a large group of specialists with numerous, important duties. From time to time these specialists would have to be replaced by others arriving on the island from the "Mainland."

Tsiolkovsky was also of the opinion that after this first island had been created, others would follow, of different dimensions, at various altitudes, including some that were very great, 100,000-150,000 kilometres.

Kondratyuk proposed creating such interplanetary stations to revolve not around the Earth, but around the Moon. These would be satellites of the satellite of the Earth. Later, similar communities might be built near other planets of the solar system, first of all near Venus and Mars. New planets might even be created to revolve around the Sun.

The creation of interplanetary stations would be of vast significance. These stations would have very important functions, some independent, and others connected with the organization of interplanetary communication.

It is difficult to overestimate the role which an interplanetary station can play in the development of science. One observatory erected on such a station would mean more than all the observatories of the entire world, taken together. Such an observatory would be beyond the Earth's atmosphere, beyond that stratum which is many hundreds of kilometres deep, and which, despite its seeming transparency, is very dusty and turbid, and is the chief obstacle in the way of many astronomical observations. It is not surprising that astronomers here on Earth so persistently climb to the top of high mountains, taking their instruments along with

them, to get to regions known for the purity of their air. The most valuable observations are those obtained by these observatories.

The dusty content of the air, which we cannot observe with the naked eye, the constant bubbling and "stirring up" of the atmosphere become a vicious evil when the eye is equipped with a powerful telescope to enable it to penetrate the depths of the Universe. It is this partial transparency of the air which, in practice, limits the possible magnifications that could be obtained with the aid of astronomical apparatus. In actual practice, a magnifying power of no more than 500 times is used, although the most powerful telescopes now in existence make it possible to obtain magnifications several thousand times greater.

Optics permits the construction of more highly improved astronomical instruments, but their perfection would prove of no value on Earth, as the image becomes faint, hazy, indistinct. The greater the magnifying power the more insufficient is the transparency of the atmosphere. For this, reason a large telescope often proves worse than a small one, and the astronomer's eye—better than the camera. Astronomers on interplanetary stations will never encounter such obstacles. And how their colleagues on Earth will envy them!

At this observatory beyond the atmosphere we will be able to obtain authentic photos of Mars and other planets, will be able completely to solve the mystery of the "canals" on Mars, and attempt to penetrate the impenetrable blanket of clouds that envelop Venus. It will be possible to check up on the correctness of the hypothesis advanced by Soviet astronomers, to the effect that Pluto is merely the largest of a group of small planets that form a second, outer asteroidal ring in our solar system. It will be possible to study new galaxies, considerably extend the boundaries of that part of the Universe that we are able to see, the metagalaxy. Just see how many absorbing problems such an observatory would help to solve!

The Earth's atmosphere is an obstacle in the way of astronomical observations not only because it is not transparent enough. The atmosphere scatters the sunlight, and although this scattering of the light gives us such a remarkably blue sky, it causes the astronomers no end of trouble. It is for this very reason that the astronomer's work-day is the night, when the sunshine does not prevent his seeing the stars and

planets. And it is for this very reason, too, that astronomers so highly value those precious moments when there is a solar eclipse, enabling them to photograph and study the Sun's corona, which cannot be seen in the bright rays of the Sun at any other time.

At our observatory beyond the atmosphere the situation will be quite different. The blinding glare of the Sun will be even brighter against the background of a velvety-black sky, and yet it will not eclipse the cold light of stars that will not twinkle but will seem to be frozen, stars that will fill the firmament in much greater number than the 3,000 which we can see from the Earth even on the "starriest" of nights. Astronomers of this observatory beyond the atmosphere will be able to see and photograph a sight as yet never seen by anyone—the solar corona when the Sun is not eclipsed by the Moon, tremendously long flames of incandescent gases, prominences that break out not from behind the dark disc of the Moon, but directly from the flaming day-time heavenly body, darkened only by a piece of cardboard. And it will be possible to make such observations not for the mere instant of a total solar eclipse,* but every day, for many hours at a stretch. And it will also be possible, at last, to study the regions of the sky that are near the Sun. In particular, it will be much easier to make observations of Mercury, which is difficult from our Earth because of Mercury's closeness to the Sun. It never moves more than 18°-20° away from the blazing solar disc.

The observatory beyond the atmosphere will make it possible to use new, more effective methods of making astronomical observations. Ever since people first began to study the sky, up to recent years, we may say, the only source of information about the heavenly bodies was their visible, and, to some extent, their infrared and ultraviolet rays. The spectral analysis of visible light led to tremendous progress in the field of astronomy, and enabled scientists to determine the chemical composition of the stars that are at such great distances from the Earth as defy our imagination. This

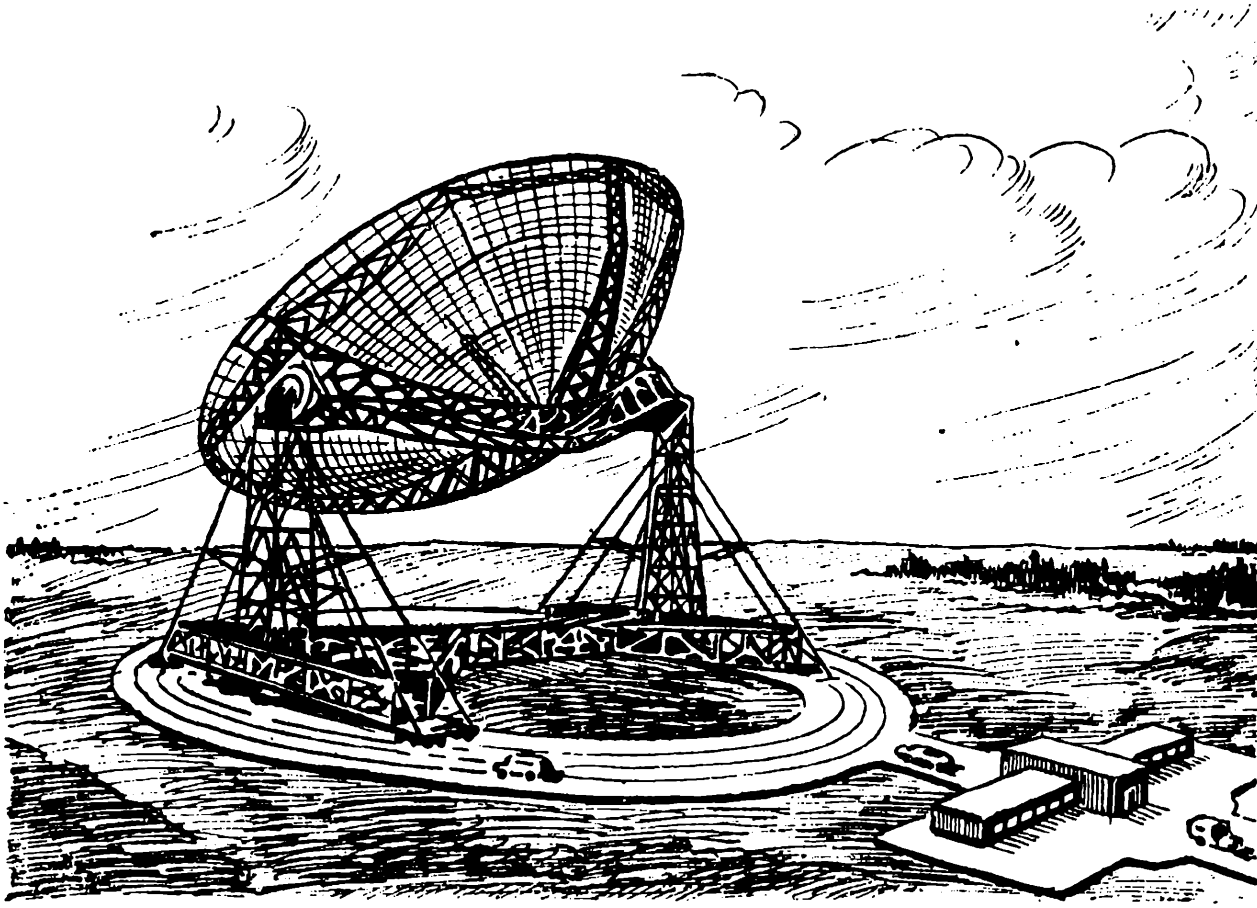
* In recent years astronomers have learned to view and photograph the solar corona not only during an eclipse. A special apparatus is used for this purpose, a coronograph, which is based either on the principle of overcoming the effects of light scattering or on the principle of using a very narrow section of the spectrum. However, observation of the corona beyond the atmosphere will be immeasurably more valuable, if only for the reason that until this very day it is possible to observe the outer corona only during the brief instant of the total solar eclipse.

spectral analysis has made it possible to determine the temperature of incandescent heavenly bodies, the laws governing their motion, the state of the atoms in these bodies. Photographs made in certain rays of the spectrum have enabled the Soviet scientist, G. Tikhov, not only to establish the existence of plant life on Mars, but even to determine the difference between Martian flora and terrestrial, and thus lay the basis for a new science of plant life on the planets—astrobotany, and many other things. And in spite of all this, it is only visible light that essentially forms the basis for all methods of observation.

Quite recently scientists took a new step towards increasing their means of knowing the Universe, a step which immediately led to truly remarkable results—the radio was applied to astronomy. This idea occurred to the Soviet scientists L. Mandelshtam and N. Papaleksi in 1928. They proposed sending a powerful radio ray up into the sky, one that would pierce the "electric ceiling" of the Earth, the ionosphere. The reflection of this ray from the celestial bodies could be registered by radio receivers on Earth in the form of a radio echo. This idea was first effected in actual practice in the United States of America in 1946, when a radio echo was received from the Moon.

But the sensitive receiving apparatuses which had been designed for such purposes also received certain radio signals even when none was sent from the Earth. As was established later, these signals came from the depths of space, the Sun and the stars themselves emitting radio waves. This laid the foundation for radio astronomy, which made remarkable discoveries within a few years: invisible sources of radio radiation were discovered, which have been called "radio stars" and "radio galaxies"; it was also discovered that non-luminous and therefore invisible interstellar gas, hydrogen, emitted these radio waves, etc.

It has recently been established beyond any doubt, that the so-called new and super-new stars are the source of especially powerful radio radiation. Mighty streams of radio beams, that come to us from the depths of the cosmos, are, in this case, the reverberations of those mysterious processes which take place within the stars and suddenly cause some of them to become inflated like a colossal soap bubble, as a result of which a modest, barely visible and, at times, completely invisible little star begins to shine blindingly in the firmament at night. It was recently discovered that a powerful radio radiation coming to us from the constellation of



Radio-telescope. Equipment to receive radio radiation of the Universe.

Cygnus was caused by the collision of two galaxies in this region of the sky.

Unfortunately, much of the radiation from space fails to reach the surface of the Earth. Actually we receive only those rays which force their way through two narrow windows, the ordinary visible light and radio waves that have a wave-length of approximately from one centimetre to 20 metres. All other rays are absorbed by the Earth's atmosphere: radio beams having a wave-length of over 20 metres, electromagnetic beams with a wave-length of less than one centimetre, the larger part of the infrared and ultraviolet rays, and the X-rays with a wave-length of less than one ten-millionth of a millimetre.

The situation is quite different as regards the observatory beyond the atmosphere. The entire spectrum of the electromagnetic radiation of a substance will, in the hands of the astronomers of this observatory, become an active weapon for a study of the Universe. It will be a powerful weapon

inasmuch as it has been established, for instance, that our system of stars, the galaxy, is much more "transparent" for certain radio waves than for the visible rays. And who knows what new forms of existence this endless matter may be discovered to have, with the aid of this means of cognition!

This is also true, in no less degree, of the corpuscular radiation of the Universe, that is, those streams of particles that come rushing down to us on Earth from the depths of the cosmos and the absolute majority of which "perish" in the atmosphere. Only beyond the atmosphere, on an artificial satellite, will it be possible to make a thorough study of these streams.

There is another form of astronomical observation which is quite impossible on Earth, but which will be a most ordinary thing at this observatory beyond the atmosphere. It will at last become possible to study a certain planet about which we know so much and yet so little. We refer to the planet on which we live. What valuable material we would be able to obtain if but one terrestrial inhabitant could look at the Earth from aside, from far away!

If we succeeded in glancing at it with the eyes of an "outsider," it would be of great help to astronomers on Earth in their study of other planets. For instance, it is sufficient to point out that astronomers know to what degree other planets are able to reflect solar light, the so-called albedo, but know nothing about the albedo of the Earth, which makes it impossible to judge of the character of the surface of the planets* with sufficient authenticity.

Not only will astronomical observations of the Earth become possible from its artificial satellite. From such a satellite it will be possible to make many observations which directly concern our life on Earth. We will be able to study many terrestrial phenomena that cannot be studied from the Earth itself. From an observation point that is at such a great distance from the Earth's surface, from this observation tower of such an unusual height, the eye can embrace tremendous areas of the Earth's surface. This presents entirely new opportunities for geophysics, cartography and meteorology. How valuable is just the mere simultaneous ob-

* We can judge of the reflecting ability of the Earth's surface only from the so-called Earth-shine of the Moon when it is illuminated by the reflected light of the Earth during the new-moon phase.

servation of the thunder regions or clouds on millions and tens of millions of square kilometres of the Earth's surface!* The weather forecasting bureau would acquire a most valuable weapon and would function much more confidently. The same holds true as regards observations of the movement of the ice in the Arctic regions, and many other observations. Some such observations are now being made with the aid of stratospheric rockets. But the value of these observations, which last but a few moments at most, is by no means comparable to the value of constant, prolonged, uninterrupted observations as made from a satellite.

In addition to astronomers, meteorologists and cartographers, there are many other scientists who would try to get to the laboratory beyond the atmosphere. Physico-chemists would have unusually favourable conditions for studying the properties of molecules and atoms, conditions as yet impossible on Earth: an unprecedented, practically absolute vacuum, a wide temperature range combined with the possibility of using the lowest temperatures for an infinitely long time, not merely during those very brief intervals that are possible on Earth today, and, furthermore, a powerful flow of electromagnetic and corpuscular radiation. Biologists and physiologists would be able to study the influence of space on various phenomena of our life; magnetologists would acquire a new means of studying the magnetic field of the Earth and, in particular, the effect of magnetic solar storms on this field; nuclear physicists would be in a "state of bliss," having at their service these powerful streams of unweakened cosmic rays, etc., etc.

An artificial satellite would be invaluable as a solar laboratory where one could study the life of the Sun and the processes taking place on it, which play such an important part in our terrestrial life. To make the most detailed observations possible it will be necessary for the satellite to make its flights around the Earth at least within the time that it takes the Sun to make several rotations on its axis, and one such rotation takes 27 days.**

* For instance, from a satellite situated at an altitude of 35,900 kilometres, that is, a satellite whose period of revolution is equal to one terrestrial day, we will be able to see about 50 million square kilometres of terrestrial surface, while the angle of vision will be only 17°.

** To the terrestrial inhabitant it seems that the Sun makes one revolution in 27 days, but as a matter of fact it lasts only 25 days. The reason for this is that the Earth itself moves around the Sun in the same direction. This is the velocity of rotation at the equatorial part of the Sun. Nearer to the solar poles it is much slower.

An exceptionally valuable feature of an observatory on a satellite would be the possibility of making constant observations without any interruptions, as it would be independent of the time of day or year and also independent of the weather, which causes so many unpleasantnesses to astronomers on Earth.

But the opportunities afforded by an artificial satellite are not confined to the observation and study of the Universe. In addition to this passive role, which, we admit, is a most important one, the satellites can play a very active part in terrestrial affairs, doing much practical good for people. At present all that is possible is to indicate some ways in which such interference in our life can be effected, but there is no doubt that in the future, as the number of satellites increases and experience accumulates, more and more opportunities will be found for using these artificial branches of the Earth in the sky.

As a matter of fact, the meteorological service of the satellites is one illustration of the very active role they can play. The use of satellites as relaying stations for television broadcasts is of no less importance. Today only those people who live within a distance of but a little over 100 kilometres from the television centre can enjoy the wonders of television, that remarkable achievement of human genius. This is due to the fact that such television broadcasts are effected by means of very short radio waves, whose length is only several metres, and which are poorly reflected from the ionosphere. That is why broadcasts on such waves can be received only in the so-called zone of direct visibility of the broadcasting station.

If the Earth's artificial satellite were to be equipped with a relaying station which could receive the broadcasts of the television centre and, in turn, broadcast them anew, the distance covered by such broadcasts could be immeasurably greater. The zone of direct visibility from a satellite is so great that five or six such relaying stations floating around the Earth along their "one-day" orbit would be able, for instance, to serve such areas with television broadcasts, as are inhabited by 90 per cent of the Earth's population. This chain of satellites could not only be used for television, but would successfully replace all the terrestrial radio and telegraph stations, would free radio communication from those disturbances which are inevitable on Earth, and would effect a saving of millions of tons of cable and wire.

By means of these satellites the solar energy could be used much more effectively in serving man. For instance, take the night illumination of big cities. Powerful mirrors set up on an artificial satellite could send the reflected solar rays to the Earth during the hours of night when, on Earth, the Sun had already set, and the satellite, flying high above the Earth, was still basking in the Sun's rays. Two or three such satellites with specially selected orbits could make the Moscow night as bright as day, without any expenditure of electric power. Eternal, free illumination!

The solar rays, directed from the satellites, could not only illuminate, but could also heat the Earth. Very thin metallic mirrors having tremendous surfaces of several square kilometres or even tens of square kilometres, could be installed on the satellites. Because of the absence of atmosphere, these mirrors would be very light. They could focus the solar beams, unweakened by an atmosphere, on a relatively small part of the Earth's surface, raising the temperature there to such an extent that ice would melt rapidly or water boil. If we had a large number of such "fire-spitting" satellites, we could count upon their active interference in the Earth's "weather kitchen," and we might, perhaps, gradually change the climatic conditions in certain regions of the Earth. With their help it might be possible to cause rain to fall or prevent it, influence the cyclonic activity in the atmosphere by creating and destroying cyclones and anti-cyclones and by changing their direction. Such interference would be especially effective if we could make the satellites hover over one and the same regions of the Earth, especially those poor in natural solar heat, as the polar regions. However, satellites can "soar" in this fashion only when flying above the equator, where there are more than enough solar rays as is.

Tsiolkovsky attached great importance to the role of satellites in solving problems of interplanetary communication. Today this role of the satellites is generally recognized. Even the simplest space flight, such as to the Moon, landing on it and returning to the Earth, is practically impossible at the present level of development of reaction technique, but we shall speak of that later. However, not only such flights, but more complicated interplanetary flights become possible even today if the satellite is used as a sort of space "service station." Supplies of fuel could be gradually accumulated on such satellites, so that space

ships could later be serviced by them when their fuel tanks became empty.

These satellites might be of equal importance as "transfer" stations for space travellers. In interplanetary communication the most advantageous flight is that which is made with one or several transfers. "Through service" in these cases is bound with very great difficulties. Incidentally, future space travellers need have no fear of making such transfers—the transfer stations will be equipped with the maximum of comfort, including the possibility of making radio-telephone calls to their terrestrial friends. The time-table for interplanetary trains would be such that it would not be necessary to wait around for any length of time at the station, but just long enough to dine; the precise work of the space travel service bureau would not, of course, permit any delays in the arrival of trains.

What will these artificial satellites of the Earth look like, these "ethereal dwellings," as Tsiolkovsky called them?

Chapter 12

ON AN ARTIFICIAL SATELLITE

> Science has developed to such a state that the sending of a rocket plane to the Moon, the creation of an artificial satellite of the Earth have become a thing of reality....
>
> Academician A. N. NESMEYANOV

It will be tremendously interesting and thrilling to live and work on an artificial satellite, and yet it will probably be not much more difficult than living at some distant wintering station on Earth. The "Little Land" will not only protect its inhabitants against the dangerous neighbourhood of interplanetary space—encounters with meteors, harmful radiation, vicious cold — but will even afford them the maximum of comfort. Thanks to robot air-conditioning plants, such a satellite will always have fresh air and warmth. Sufficient experience in this direction has already been accumulated. The air will be purified so that it will not contain the harmful products we exhale; it will be enriched with oxygen and the nec-

essary moisture will be added to it; it will even be saturated with light, pleasant aromas, so that the dwellings on the satellite will be filled with a fresh embracing atmosphere as that of a spring morning or of a warm autumn evening, fragrant with the scent of distant flowers.

But it is not only tanks of liquid oxygen that will supply this "elixir of life" on the satellite. Tsiolkovsky advanced the idea of, and even made calculations for, a hot-house whose plants would be able to absorb the carbonic acid exhaled by the inhabitants of the satellite and which would produce the life-giving oxygen* with the help of the chlorophyl grains of green leaves. This wonderful cooperation between the plant and animal worlds, transferred from the Earth to the satellite, will not only ensure its inhabitants fresh air and supply them with fruit and vegetables, but will also beautify the satellite with an eternally blossoming garden and will fill the vases in the "apartments" of the passengers with fresh flowers.

The absence of air outside the satellite will enable its inhabitants to make small excursions in world space at will. In order to do so they will have to wear special space suits that resemble a diver's suit, but which will be much more intricate in design.**

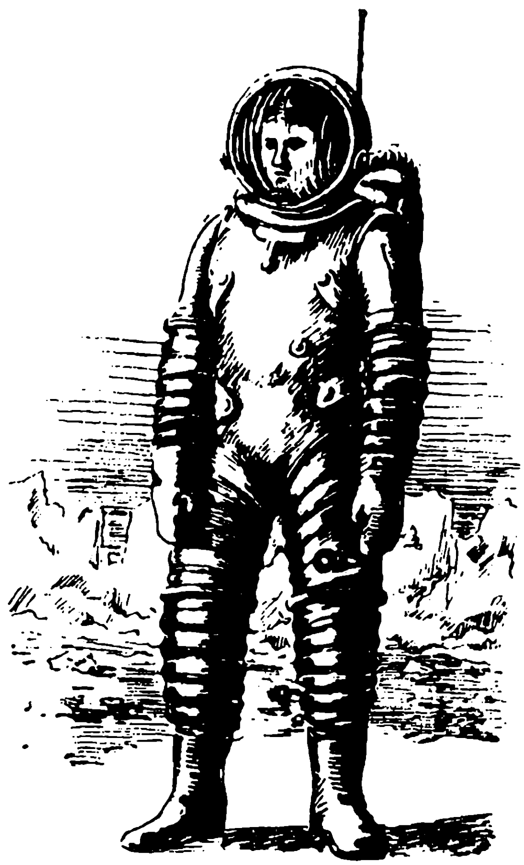
The fabric of these suits must be sufficiently durable to withstand the blows that may be dealt it by minute heavenly stones, and also to withstand the pressure within the suit, which will be created by an air-conditioning apparatus. The fabric of the suit must also protect the wearer against the harmful effects of various rays which penetrate space. It may be feasible to make the interplanetary suit of metal with flexible folds in all the joints.

Through the hatch, which serves as a unique sort of "canal-lock," the passengers on the satellite will make their way out, becoming independent satellites of the Earth. Many valuable scientific observations can be made

* Developing these ideas of Tsiolkovsky's, Tsander, back in 1915-17, built a hot-house of an astronautical type and grew vegetables in it.

** This was also one of Tsiolkovsky's ideas. It is interesting to note that suits which greatly resemble the future interplanetary suit are already being used in aviation by high-altitude pilots. Their purpose is to save the life of the pilot in case anything goes wrong with the hermetic cabin. If the pressure in the cabin should suddenly drop, the suit automatically becomes inflated. This enables the flier to lower his plane to a safe altitude and sometimes even to continue his flight for a long time.

only there, beyond the walls of the satellite. And generally speaking, it will be of great value to be able to move about outside the satellite, as, for instance, when repairs must be made on the outer part of the satellite, when new equipment must be erected on the exterior surface, or when construction work is going on during the building of the satellite, etc. The cumbersome suit of the astronaut must, therefore, permit free movement of the hands, feet, and even the fingers.


Space suit for interplanetary travel may look like this.

Every excursionist will have to be supplied with various equipment necessary for a sojourn of several hours outside the satellite. A small tank of oxygen, a minute receiving and transmitting radio-telephone station, and lights for illumination outside the satellite, which may prove useful if it becomes necessary to examine that part of the satellite's surface which is not illuminated by the Sun; a pneumatic pistol, not for hunting cosmic hares, to be sure, but to help the excursionist move farther away from the satellite by making use of the kick of the pistol when it is fired—such is the approximate equipment of every "swimmer" in space. Heavyish? By no means, for everything on the satellite, including the excursionists flying about beside it in space and who seem to be tied to the satellite by invisible threads, will weigh absolutely nothing.

But this weightlessness, which is a convenient phenomenon in the given case, is, perhaps, the most unpleasant aspect of life on the satellite.

What does the expression "it has no weight" actually mean? Can it be that the passengers on the satellite and all the objects on it are no longer attracted by the Earth? No, of course not; they are attracted as formerly and only at altitudes many times greater does the force of attraction become considerably less. There is something else that must be considered here.

What is it that gives us weight on Earth? It is the support beneath us, the floor, a chair, the soil, etc., which prevents us from falling to the centre of the Earth, where we would absolutely find ourselves as a result of the force of gravity were it not for such support. It is the pressure we exert on this support that is our weight. Should you like us to do so, we can measure this force: it is sufficient simply to place a strong spring beneath the support. Under the pressure of our weight the spring will be compressed, and if we know what force is necessary to compress it, we will also know what our weight is.

Remove the support from beneath our feet and we will immediately begin to fall towards the centre of the Earth. We will fall faster and faster and the velocity with which we fall will increase rapidly—10 metres per second for every second we fall, if we ignore the resistance of the air. That is what we call the acceleration of a free fall.

What will happen to the spring if, together with the support beneath us, we really do take a free fall, that is, if we fall towards the centre of the Earth without anything in our way to stop us? Obviously, the spring will no longer be compressed, since the support no longer stops us from falling.

Let us imagine another way of falling, when the spring is compressed, but less than in the beginning, for instance when the spring is compressed to one half of what it was before. This means that we weigh half as much as usual. In this case we will fall towards the centre of the Earth not with the acceleration of a free fall, but with an acceleration that is half as much—our velocity will increase five metres per second every second.

Can the spring become compressed more than in the beginning, that is, can we weigh more than usual? That is exactly what will happen when taking off in a space ship (just recall Jules Verne's cannon).

So we see that the compression of the spring enables us to judge of the magnitude and direction of the acceleration of our motion. This often becomes very necessary and not only in astronautics. An important apparatus has been built on the basis of this principle, the accelerometer, which is used to measure acceleration. Not a single space ship will set off on its journey without this apparatus. In the accelerometer a massive ring that rests on a spring slides along a smooth pin. An arrow attached to the ring shows the degree to which the spring is compressed and, it follows, the magnitude of the acceleration of the motion of the accelerometer.

Let us suppose our accelerometer has been installed on our rocket. At first the rocket stands motionless on Earth, and the accelerometer arrow points to 1. This means that only the usual weight of the ring affects the accelerometer spring. Then the rocket takes off. The spring is compressed and the arrow no longer points to 1 but, let us say, to 4. In other words, the acceleration of the escaping rocket is four times the acceleration of a free fall, and the weight of the ring is 4 times its usual weight. * But now the rocket motor has been shut down, and the rocket begins to fall freely to the Earth (while doing so it will, of course, continue to move upwards in the beginning because of the velocity it has accumulated, then it will stop for an instant, and finally begin to move down towards the Earth); the accelerometer arrow points to 0; the spring is not compressed at all now, and the ring has no weight whatever.

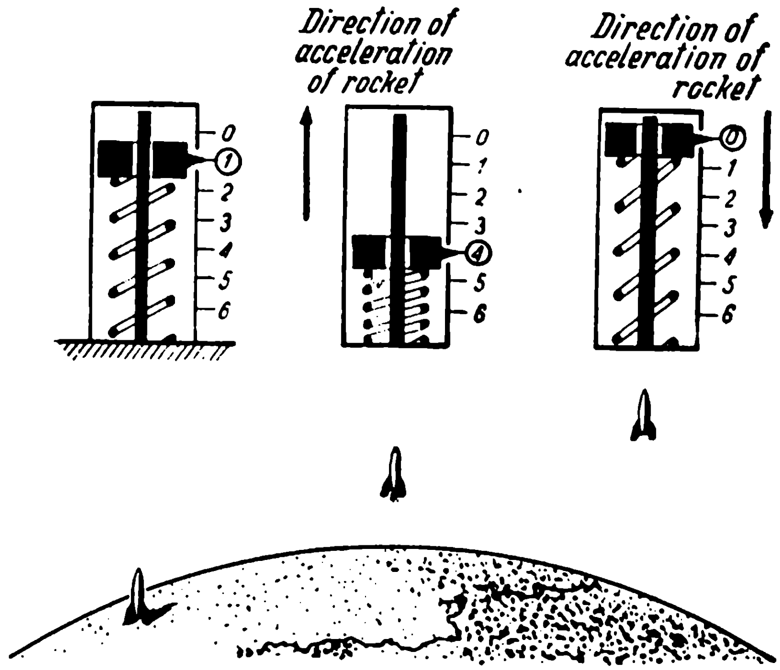
The very same thing takes place on a satellite, for together with everything on it, it falls freely to the Earth. Everything on such a satellite is weightless, and this fact makes life on the satellite not only unusual but, we must admit, even unpleasant. Very likely (we shall speak of this in Chapter 20, which is especially devoted to this problem, one of the most important in interplanetary communication) a person cannot remain in a state of weightlessness for a long time, and measures must, therefore, be taken artificially to create weight on the satellite.

The absence of weight on the satellite destroys one's conception of what is up and what is down, a feeling so customary to people on Earth. And in order to walk on one's feet and not on one's head, it may be necessary to put magnetic soles on one's shoes. Incidentally, the very conception of the term "to walk" is, under these conditions, also unusual. On Earth we move about because of the friction between the soles of our feet and the soil, but this friction results only from the fact that our weight presses us to the soil. If there were no weight, there would be no friction, and the usual walking would be impossible. It will probably be necessary to put a number of handles and loops on the walls of the cabins and corridors

* During a vertical take-off the rocket speed will be increased not fourfold as during a free fall, but only threefold, for the acceleration acquired by the rocket when its motor is operating is opposed by the acceleration of a free fall.

Therefore, if the arrow of the accelerometer points to 1 during flight, it means that the rocket is simply suspended motionless in the air. We shall tell you more about this influence of the Earth's attraction in Chapter 16.

of the satellite to aid people in moving about. These walls, as well as the floors and ceilings (incidentally, the distinction between these words becomes quite conditional), will have to be padded with a thick layer of soft upholstery, for otherwise a careless move by the satellite's inhabitants may send them off into the most unexpected direction and they may end up by becoming covered with abrasions and bruises.



Apparatus permitting one to judge of acceleration of interplanetary ship and of weight of its passengers. This apparatus is called an accelerometer—"accelerating gauge." At left—the ship is standing still or moving with constant velocity. The accelerometer arrow points to 1; the weight of passengers is normal. In middle—the ship takes off; its velocity continually increases. The accelerometer arrow points to 4, signifying that passengers' weight is four times the normal. At right—the ship flies with the motor turned off, consequently it falls freely to the Earth. The accelerometer ring has no weight, indicating that the passengers of the ship have no weight. The arrow points to 0.

On Earth the force of gravity causes a constant thermal stirring up of the atmosphere. If provisions are not made for an ingenious ventilation system for all the premises on the satellite, the people will suffocate in the products that they themselves exhale; they will suffer from the heat as they will be "enveloped" in an immobile stratum of air heated by their own bodies, and it will be impossible to light a match or a cigarette because of the absence of oxygen.

In order to drink it will be necessary to use special tubes through which one can suck up the liquid, or resilient bulbs that look like rubber pears or tooth paste tubes and from which it will be possible to squirt the liquid right into one's mouth. Water will not pour out of a jar into a glass set beneath it, but if, in spite of all, it should pour out, the water will

not fill the glass as we are accustomed to filling it on Earth, but it will move against the walls of the glass or will collect in a ball under the influence of surface tension. An unguarded movement, and globules of water, soup or cocoa of all sizes will begin rolling about inside the cabin in all possible directions.

However, "weight" will probably be artificially created on the satellite and its inhabitants will be spared these "exotic" experiences. Numerous designs for the Earth's artificial satellites have already been proposed. It is likely that satellites will, in the future, be created for diverse purposes.

The simplest will be robot satellites without people. They will make their endless circular trips around the Earth in eternal silence. Such satellites will be the first to reach their cosmic orbits. These orbital cosmic rockets will make it possible to perfect the method of launching them and of studying their flight, and it will be possible to check up on and organize radio communication with such rockets. Means of protection against many dangers that accompany a sojourn in space will be tested by these rockets; it will be possible to determine the effect of encounters with meteors, the effect of cosmic and all other radiation on the construction materials of the rockets, the temperature variations of the rocket jacket, and many other questions of primary importance. By means of these most simple satellites it will be possible to make scientific observations in the fields of astronomy, geodesy, physics, radio engineering, etc. All the necessary data recorded by the instruments will be transmitted to the Earth by radio.

The next step will be experimental landings on Earth by such radio-controlled robot satellites, equipped with wings which can also be retractable. The starting and stopping of the motors of these rockets can be effected either automatically or at a command from the Earth.

But besides using robot satellites for experimental purposes, which will mark the beginning of the conquest of space, even later, when numerous satellites inhabited by people will revolve around the Earth, robot satellites will continue to find wide application. Such satellites will probably serve as cosmic fuel storage houses, as searchlights to illuminate cities, and as relaying stations for radio and TV broadcasts. And only from time to time will the workers of the "road" service department for interplanetary communication visit them on their cosmic speed ships bearing the inscription "Service" on their broadside, to inspect all these artificial cosmic bodies created by man to serve man.

As a rule it will be feasible to select such an altitude for the satellite's orbit, as will enable the satellite, within the course of one day, to make a number of complete revolutions around the Earth for the convenience of its observations. For instance, at an altitude of 557 kilometres the satellite will fly around the Earth 16 times while the Earth will make one rotation on its axis (such an orbit will take $1^1/_2$ hours); at an altitude of 1,669 kilometres—12 times (an orbit of 2 hours), etc. A rocket train of three or four steps with motors operating on the usual fuels, such as we know of today, is sufficient to launch the simplest orbital rockets. It is quite possible to construct such trains at the present level of development of reaction technique. Values for the fuel-weight ratio of the rocket which have already been achieved are fully acceptable.

If the rocket standing on Earth is to become an artificial satellite, it must obviously spend a certain amount of energy. This energy will be spent on raising the rocket to the altitude of its orbit, imparting to it the necessary circular orbital velocity, on piercing the "armour" of the atmosphere, that is, on overcoming the resistance of the air, and on compensating for various other losses of energy, which are inevitable during such a flight. The energy necessary for all these purposes must be contained in the fuel stored up on the rocket. What should the value of this energy be?

If the rocket flew in free space where there is no air or any force of gravity, all the energy of the fuel stored up on the rocket would be spent only on the take-off run of the rocket and on increasing its flight speed. In this case the final velocity of the rocket would obviously be much greater than the velocity of the rocket as it flies off from the Earth. It is not surprising that this velocity is often called the "ideal," to show it is unattainable in reality.

In astronautics the fuel supply on a rocket necessary to make any interplanetary flight is usually based on the value of the ideal velocity. The more complicated and the more difficult the flight, and the greater the energy to be spent on effecting it, the greater will be the amount of fuel to be stored on the rocket, which, in turn, means that the ideal velocity of the rocket will be that much greater.

If a rocket is to become an artificial satellite of the Earth, the value of the necessary ideal velocity of the rocket will depend chiefly on the altitude of its orbit above the Earth. Calculations show that this velocity

increases from 8 to about 13 kilometres per second when the altitude of the orbit increases from 0 to 35,000 kilometres.

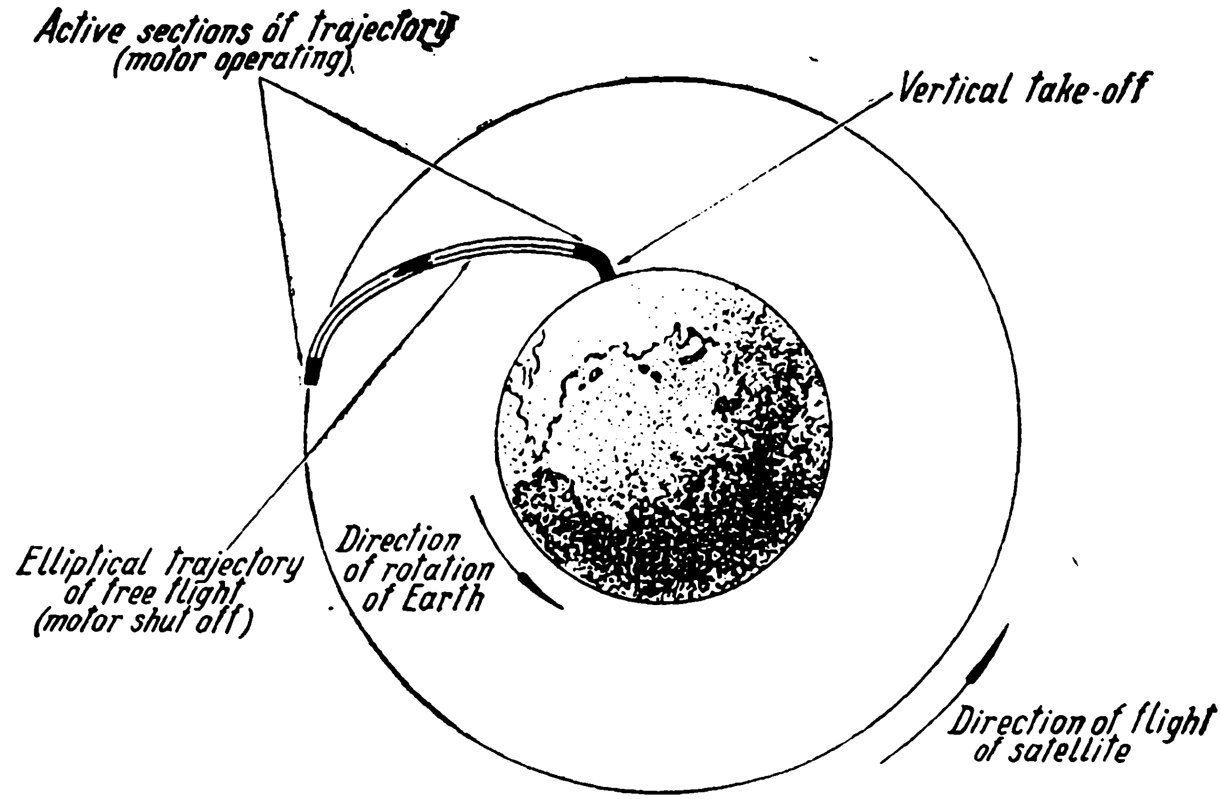
The methods which can be used to achieve the necessary velocity are known to us. They have been defined by Tsiolkovsky's formula, namely, to increase the jet velocity of a liquid-fuel rocket motor and increase the fuel-weight ratio of the rocket.

Let us once more recall the long-range rocket described in Chapter 6. The ratio of the take-off and final masses of the rocket is 3.25, and the jet velocity is approximately 2,100 metres per second. Tsiolkovsky's formula shows that a rocket which could become a satellite that would revolve around the Earth at an altitude of 500 kilometres must, at the indicated mass ratio, have a jet velocity of 7,000 metres per second, which is unattainable by modern reaction technique. If we retain the value for the jet velocity given above, namely, 2,100 metres per second, the mass ratio must be approximately 60, which can be obtained, although not without much work, by means of three- and four-step rockets.

The flight of such a rocket along its orbit will very likely resemble the flight of the long-range rocket already mentioned. The rocket will take off vertically; then, at a certain altitude, it will begin to fly at an angle with the horizon until it has acquired the velocity sufficient for it to attain the necessary orbital altitude when continuing in a free flight. When this has been reached, the motor is turned on again so that the rocket's flight velocity in its orbit will become circular. In this case the motor works for a very brief period, but twice, at the beginning and at the end of the trip. *

In order to take advantage of the velocity which the Earth has as it rotates on its axis, the satellite's flight in its orbit should be in the same direction as the rotation of the Earth, that is, from west to east. The maximum gain in velocity in this case may be at the equator, and will be equal to approximately 465 metres per second. The greater the geographical latitude of the launching point of the rocket, the less will be this gain. A flight in the opposite direction will mean an equal increase in the necessary ideal velocity. If the take-off is at the pole, the direction of the flight will, of course, in no way affect the value of the ideal velocity.

* We can launch the satellite in a different way: for instance, the original ascent of the rocket can be effected by means of an aerostat or airplane, and the final push (the run until it attains its orbital velocity) can be achieved by means of an explosion of a special charge in the rocket.



Trajectory of flight of orbital rocket.

The building of orbital satellite rockets of the smallest dimensions is not only fully possible today but does not even involve any special difficulties. In the simplest case the only thing necessary on such a rocket is the steering gear; the useful load, in this case, will be 0.

According to one of the designs, by using a three-step rocket having a total weight of 17 tons* at take-off, it will be possible to build an artificial satellite three metres long, with a diameter of 0.5 metre and weighing 70 kilogrammes, to revolve around the Earth in an orbit at an altitude of 800 kilometres. Satellites of even smaller dimensions can be built. For instance, according to a statement by the National Academy of Sciences of the U.S.A., during the International Geophysical Year, which will last from July 1957 to December 1958, attempts will be made to launch robot artificial satellites the size of a basketball. It is planned to install instruments on them to study the phenomena of the Earth's atmosphere and of the Universe.

These satellites are to revolve around the Earth for several days at an

* According to other calculations the take-off weight of such a rocket, using fuels available today, must be equal to 100 tons.

altitude of 350-500 kilometres, at a velocity of approximately 30,000 kilometres per hour.

Academician L. Sedov, Chairman of the Joint Committee of the Academy of Sciences of the U.S.S.R. on the Coordination of Research Work in the Field of Interplanetary Communication, has stressed the fact that, from the technical viewpoint, it is possible to build a satellite of greater dimensions than those indicated in the statement of the Academy of Sciences of the U.S.A., and he has pointed out that the realization of the Soviet project can be expected in the relatively near future.*

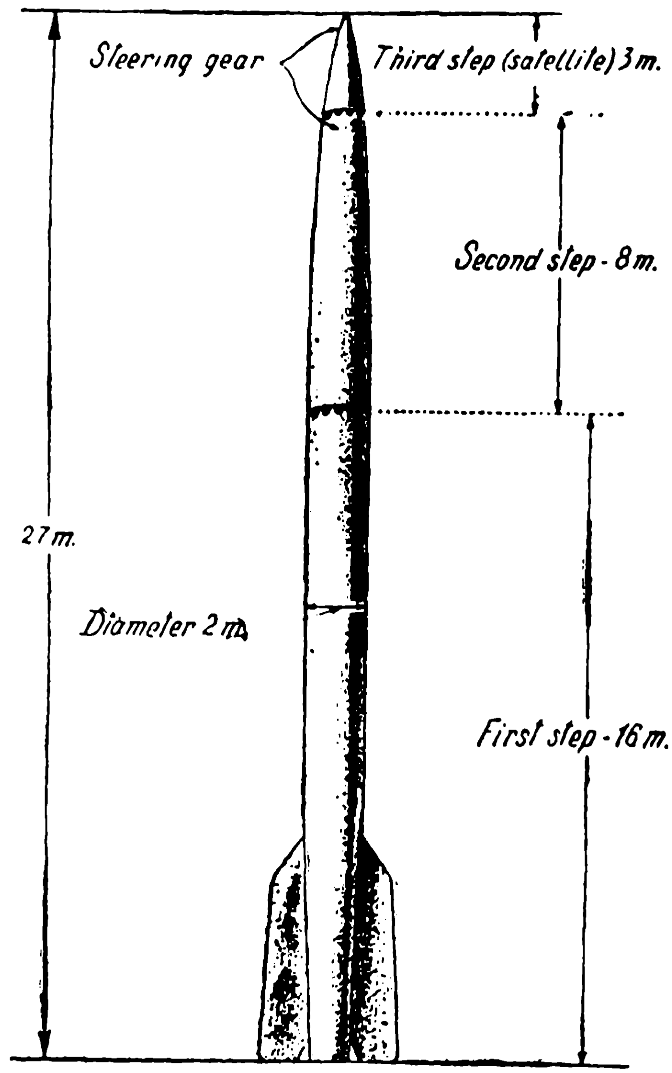
It is interesting to note how greatly the slightest load on the satellite complicates the task. If just a few of the most important instruments, having a total weight of 100 kilogrammes, were installed on the half-metre satellite discussed above, this pay-load of 100 kilogrammes would increase the take-off weight of the rocket train almost fourfold, from 17 to 65 tons. It is, therefore, understandable why exceptionally light equipment must be installed on the robot satellite. The latest achievements in the field of radio-electronics unfold special opportunities in this connection. These achievements concern replacing the usual vacuum electronic lamps by metallic semi-conductor instruments whose dimensions and weight are insignificant and which consume very little electric power.

In such a rocket the ratio of the take-off weight of the train to the weight of the useful load would be 650. However, this ratio can be decreased in the future, which is, of course, extremely important. It is considered that the development of reaction technique will make it possible to build a three-step rocket in which for every ton of the pay-load of the last step, that is, the satellite, there will be 200 tons at the take-off. However, if this is to be achieved, there will have to be improvements in the fuels used and also in the rocket design.

The first orbital rockets that will carry people will very likely resemble the robot satellites in many respects. After making their flights around the Earth within a certain period of time, these rockets will land on Earth. Such a landing will necessitate the use of wings in order to glide in the atmosphere, and a certain amount of fuel for changing to a free flight and for braking when landing.

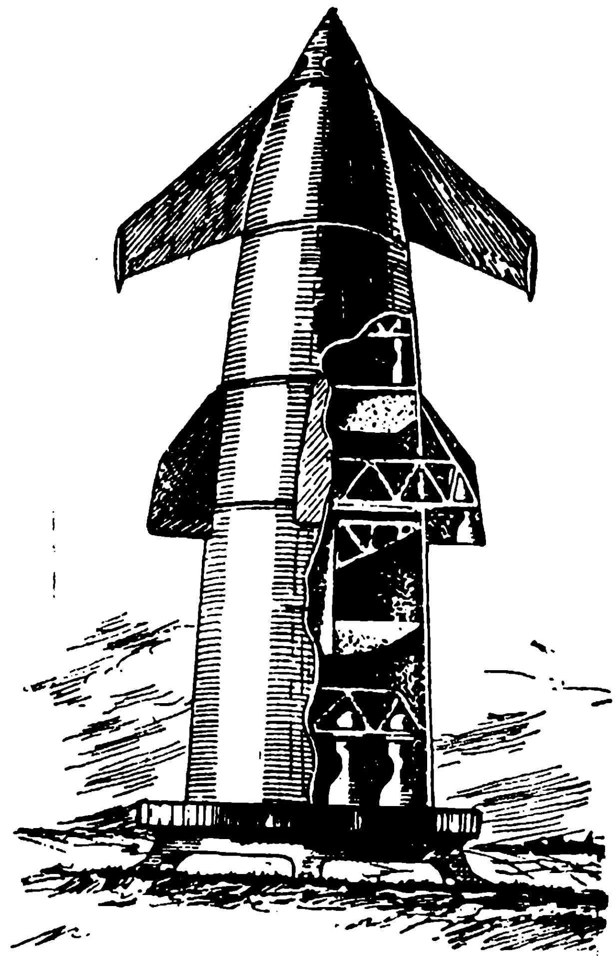
* Problems of the creation of an artificial satellite are also being studied by the Astronautical Section of the Central Aeroclub of the U.S.S.R., a public organization of scientists, engineers and students—astronautic enthusiasts of the Soviet Union.

If the number of steps of the rocket train were increased, its take-off weight would be decreased, while the value of the useful load of the last step, that is, the orbital rocket, would remain the same. Thus, according to one of the projects, when the useful load of the orbital rocket is 3.5 tons, the take-off weight of a four-step train should be equal to 870 tons (the ratio of the take-off weight to the useful load would be 250). The length of such a train is 35 metres, its maximum diameter—11 metres, and the total time during which all the motors operate—844 seconds, with a fuel expenditure of 710 tons. In this case nitric acid and hydrazine, with a jet velocity in a vacuum of 3,000 metres per second, should serve as the fuel. The first two steps of such a train may descend to the Earth by means of parachutes and can be used again; the third step will fall to the Earth and be smashed; the final step will become the satellite at an altitude of 1,669 kilometres, which corresponds to a period of revolution of two hours. This last rocket may have wings if there are people on it and if it is intended to land on Earth.



Last step of this three-step rocket may become the Earth's satellite.

Of course, the creation of a permanent satellite with people on it, a whole interplanetary station, is immeasurably more difficult than the launching of simple orbital rockets. Such a station, equipped with everything necessary, will have to weigh hundreds and, perhaps, thousands of tons. One can hardly expect to build such a station on Earth and send it by means of rockets to an orbit at an altitude of hundreds or even thou-



Project of four-step orbital rocket with pay-load of satellite equal to 3.5 tons.

sands of kilometres. Such a train would weigh hundreds of thousands of tons at the take-off. Obviously it will be necessary to build such a station on Earth, test it, then take it apart and send these parts off by rockets to the orbit where the station will be assembled.

Such a "construction job" in space will be an unprecedented undertaking, gigantic in scale, unusual in its difficulties. It will be necessary not merely to create a new heavenly body, the Moon's younger sister, but one on which people can live, a settlement for human beings. The path, dimensions and velocity of the motion of this heavenly body will be set by man. What a triumph of science this will be! This star will not appear in the telescopes of astronomers who study the heavens; it will first appear on the drafting boards of engineers and scientists, and will be built at the "Little Moons lant," later to be assembled in interplanetary space.

It will take many months or, perhaps, years to build this "structure without a foundation," a structure unknown in the history of building technique. Hundreds, perhaps even thousands of freight rockets will deliver all the necessary equipment and the parts of the station to the building site beyond the atmosphere. The builders of the station will live in small orbital ships that will form a unique dwelling community whirling around in space in direct proximity to the building site. When going to work the builders will wear their cosmic working clothes, the space suits described above, which will be fitted out with the necessary instruments. It may be desirable to supply the erection men with special footwear having electromagnetic soles to enable them to stand on the surface of the future satellite.

We must not underestimate the difficulties attending the building o such an artificial satellite. If it is fully possible, at the present time, to launch small orbital rockets from the Earth, both robot rockets and others with people, we cannot say the same as regards the building of large interplanetary stations, which, as we have pointed out above, will have to be erected beyond the boundaries of the atmosphere, in space. Such a building job involves not only tremendous technical difficulties, but also difficulties of an astronomical nature.

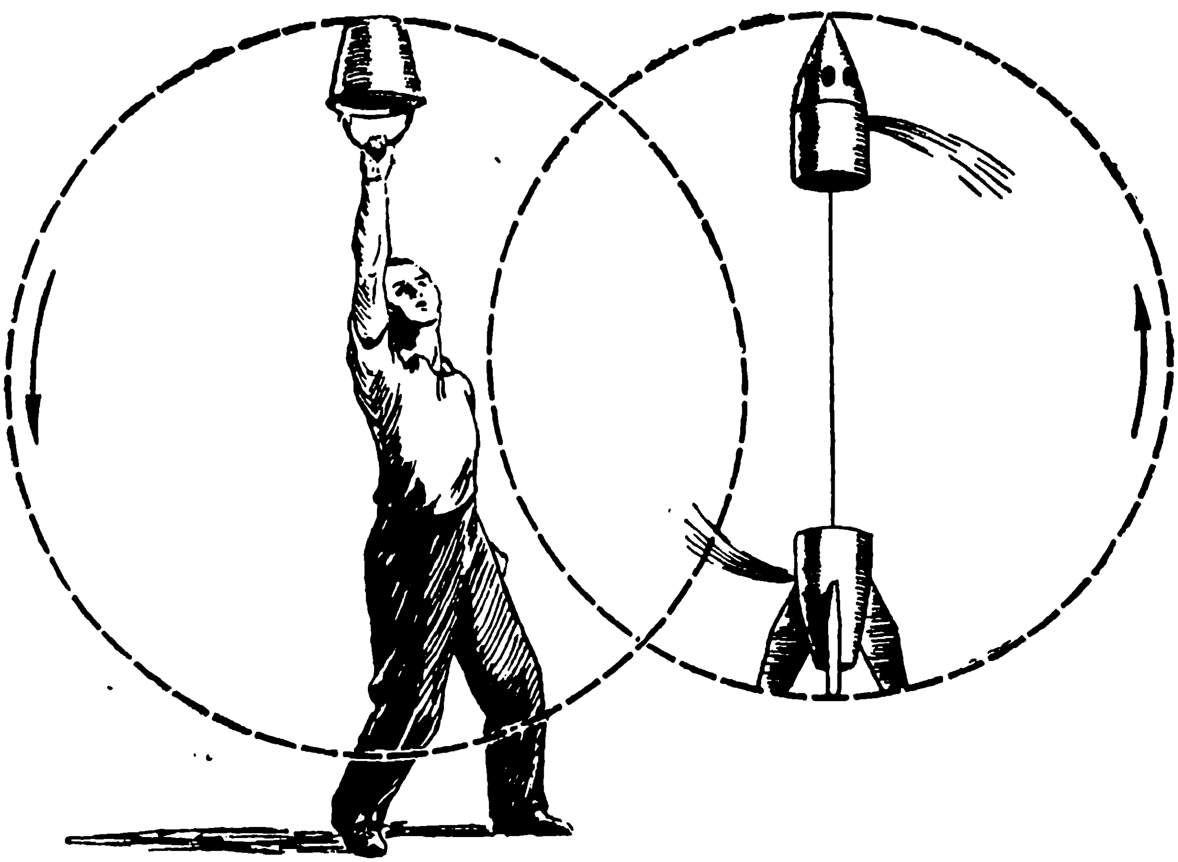
It is not such a simple matter to overcome these difficulties, and the builders of an island at the shores of the Earth will have to display great ingenuity and skill. They will have endless difficulties. And yet, despite the gloomy pessimistic asseverations of certain scientists, it will be possible to create such satellites.

Scientists, engineers and inventors have various ideas regarding the exterior appearance and design of an interplanetary station. Some conceive of it as a cylinder with hemispheres at the ends (Tsiolkovsky); others—as having four parts connected by girders (Kondratyuk); still others conceive of it as having the form of a sphere, a wheel, a cigar and other intricate geometric figures. But all of them strive to overcome the phenomenon of weightlessness on the satellite, they try artificially to create the sensation of weight, and for this purpose use the only means possible—rotation. In fact, that very physical phenomenon which deprives the satellite of its weight is used again to restore that weight.

In Chapter 3 we spoke of inertia overloads that arise when the velocity of motion sharply changes its magnitude or direction. These overloads may increase our weight manifold when the cosmic ship takes off, but they can also restore our weight when it vanishes on the satellite. In order to attain this end, we must make the satellite rotate in such a way that the acceleration which arises during the rotation will be equal to the acceleration of the Earth's attraction. Incidentally, this acceleration may be less, in which case the weight on the artificial planet will be less than the terrestrial weight and equal to, let us say, the weight on Mars or on the Moon. The idea of creating artificial gravity in the form of the force of inertia which arises during rotation also originated with Tsiolkovsky.

It should be pointed out that the rotation of the satellite involves many inconveniences—greater intricacy in design, difficulties of making sci-

entific observations, especially astronomical and others. It is only the need of creating artificial weight in order that the human organism might function normally for a long time, a need confirmed by experiment, that may make the introduction of rotation necessary.



Artificial load created by rotation.

As regards the shape of the satellite, the one that most readily and most frequently occurs to the mind is the sphere. It will require the least amount of construction materials and will afford a number of other conveniences. A sphere having a diameter of 20 metres should make from 5 to 10 rotations a minute on its axis, so that the weight on it (at the "equator") will be equal to the weight on Earth or will be equal to half of it.

Another popular idea is that of building the satellite in the form of a tremendous wheel, a "doughnut" or torus, as a body of such a form is called in geometry. This wheel may have a relatively large diameter,

60-70 metres, and may, therefore, rotate on its axis at a low speed or at the speed of the second-hand of a clock. For the inhabitants of such a wheel the outer felly would be the floor, and the inner one—the ceiling.

It has also been suggested that the satellite be built in the form of colossal Indian clubs, similar to those gymnasts practise with. In this case two large passenger compartments (or only one of them for passengers) are united by a tube and rotate about a common centre of gravity. Sometimes simple guys may be used in place of the connecting tube between the passenger compartments.

The work of assembling the massive parts of the satellite in space will be greatly facilitated by the absence of weight—no cranes, no pulleys or scaffolding will be necessary. However, one must never forget that the absence of weight does not make the parts of the satellite less massive. Should the erection man forget about the law of inertia, he might find himself in a bad fix if, through his carelessness, he should be squeezed between two massive parts of the satellite.

The absence of weight will not only simplify the assembling of the satellite, but will also make it possible, in many cases, to simplify its construction: to use hollow parts, decrease their cross-section, etc. At the same time it will be possible to use astronomical apparatus of much greater dimensions than are possible on Earth. Some telescopes used on Earth weigh over 100 tons as they must be massive to increase their rigidity and to decrease deformations resulting from their own weight. A mirror of much larger dimensions than that used on Earth can be assembled on the satellites from the parts delivered from the Earth, and then silvered and polished; a telescope with such a mirror may weigh much less than even small telescopes on Earth.

One of the most serious problems will be to supply the satellite with the power necessary for the numerous research plants and to satisfy the everyday needs of the inhabitants. Apparently, the usual thermo-power plants used on Earth will not do for this, as they require air for their operation.

The motors to be used on the satellite, as, for instance, those necessary to start the rotation of the electric generator which feeds the numerous electric motors, will have to operate on a fuel that burns without air,

that is, the same fuel as is used by cosmic rocket motors. It will be quite possible to use gas turbine motors, which operate on the products resulting from the combustion of such fuels. But, of course, even such motors do not solve the problem fully, for the fuel necessary for their uninterrupted operation is obtained at a very high price—it must be delivered from the Earth.

The wisest solution of the problem, of course, would be to build such a power plant on the satellite as did not require any fuel.

There are several ways of solving this task. For instance, an atomic motor could be used, as it consumes an insignificantly small amount of fuel.

Atomic batteries, which are already obtainable today, could be installed on small robot satellites. These batteries use the so-called volt-electron effect, as a result of which atomic energy is converted directly into electric enegry. Any artificial radioactive substance which radiates electrons serves as the basis for such a battery, as, for instance, the strontium radio-isotope obtained in atomic reactors. For this purpose a thin layer of strontium is deposited on the surface of the semi-conductor, which may be an especially treated quartz. When passing through the lamina of such a semi-conductor, every electron that comes flying out of the strontium evokes a "shower" of the hundreds of thousands of electrons that are contained in the semi-conductor. As a result we get an electric current. This weak current can be considerably increased if several similar "atomic elements" are collected in one battery, as has been done in apparatus already built to feed radio instruments and for other purposes. Inasmuch as a strontium atomic battery can operate uninterruptedly for many decades and is very small in size and weight, we can readily understand why its use on robot satellites should arouse such interest. However, on large inhabited satellites powerful atomic motors of another type will have to be installed. Atomic motors of tremendous power and of very small dimensions have already been created; they will be very suitable for use on satellites.

It is quite likely that direct use will be made of the solar energy, of which there is so much in the space near the Sun. A contributing factor is the fact that the night on a satellite is very short. For night on the satellite sets in only when the satellite is in the shadow cast by the Earth. For the satellite, the night is a total eclipse.

A most attractive idea is that of building a power station on the satellite, in which the energy radiated by the Sun would be directly converted into electric power. Science knows how this can be done, and there are several ways of accomplishing this.

For instance, it is possible to use a photo-electric cell for this purpose, one in which the light energy of the Sun would be directly transformed into electric energy. However, before this can be done it is necessary to make considerable improvements in the photo-electric cells which, as yet, give very little current.

Another method would be to use the thermocouple in which thermal energy is transformed into electric power. It is a known fact that if the joint of wires of two different, especially selected metals, as, for instance, iron and a constantan alloy, or platinum and rhodium, or certain other metals, were heated and another joint of these same wires was maintained at a lower temperature, current would flow in the electrical circuit composed by these wires. The strength of this current will depend on the couples of metals used, and the difference in temperature of both joints, the hot and the cold. This property is widely used today in measuring the temperature in machines, furnaces, laboratory apparatus. So-called thermocouples are made for this purpose.

The application of this principle for the direct transformation of thermal energy into electrical is very attractive because in many cases the cumbersome, intricate thermal engines would become unnecessary. However, this method of obtaining electricity is now very rarely used on Earth, for it is less profitable: only a small amount of the heat is used as yet.

The situation is quite different as regards the future, when the use of thermocouples will make it possible more fully to transform heat into electricity.

The use of semi-conductor photo-electric cell and thermocouple generators of electric current, which use the solar energy, affords especially bright prospects. Such generators as are capable of supplying a small artificial satellite with electric energy can already be built today.

For instance, if one joint of a semi-conductor thermocouple were to be heated by solar rays concentrated by a reflecting mirror (which can be made of tin), and if another were placed in the shade, it would be possible to obtain energy in the amount of 100 watts per square metre of mirror

surface. A semi-conductor electric battery with photo-electric cell will be able to produce the same amount of energy.

It is most likely that for large interplanetary stations and also for robot satellites of large dimensions, solar thermo-power plants will be used, similar to those which are coming into ever greater use on Earth, in particular in the southern regions of the U.S.S.R. In such a plant the solar rays are collected by a mirror and directed to the steam boiler installed in the focus of this mirror. The liquid flowing in the pipes of the boiler, as water or mercury, evaporates and moves to the steam turbine which sets the electric generator into operation.

The waste steam once more becomes transformed into a liquid in the condenser, so that the working liquid is not expended but keeps circulating all the time in a closed circle. Calculations show that such a plant today is much more effective than any other which can be installed on a satellite. The power of such a plant varies greatly, from one-two kilowatts for small robot satellites to thousands of kilowatts for tremendous space stations.

Such a solar plant could be erected right on the satellite, for instance in the centre of the wheel mentioned above. However, in this case certain difficulties will arise, connected with the rotation of the satellite, for the mirror must always be "looking" at the Sun. It can also be assumed that if the rotation of the satellite to create artificial weight should prove necessary after all, many auxiliary enterprises of the interplanetary station may be located not on the satellite itself but at a small distance from it. Then the satellite with all its "population" will be able to rotate as much as it pleases; it will simply be the centre of a whole interplanetary community, a small archipelago of islands.

In this fashion the satellite will whirl around the Earth in space, surrounded by its auxiliary service stations. The list of such service stations may be rather long. It will include the power station for the entire community, which will be either solar or atomic. And there will be a huge fuel storage house to service space ships. Then, there is the observatory. And a tremendous mirror-searchlight to illuminate the Earth. Then, too, there will be radio stations for relaying radio and TV broadcasts, for communication with the Earth, with space ships, with the planets, and also for radio-astronomical and radar observations. These auxiliary structures may be either stationary or they may rotate ac-

cording to their own laws, as when following the Sun, the stars, etc.

The inhabitants of the satellite will visit these stations by using small service ships or they may simply go "on foot," when clad in the necessary suits. These service stations may be connected with one another and with the satellite by electric cable for the transmission of power and by other means of communication. There will be great opportunities, in this case, to transmit power without using wires, for in space transmitted power will not be lost or dispersed. Tsiolkovsky, in his day, proposed using streams of cathode beams, that is, electrons, for this purpose. The achievements of radar make possible the transmission of high frequency electro-magnetic power, generated by means of radio lamps, practically without any losses, and in this case the energy transmitted may be quite significant, amounting to hundreds and thousands of kilowatts. The invisible radiant streams of the power transmitted in this way can also be used to feed the reaction motors of the service ships and even small motors with which any "swimmer" in space may be supplied.

It may even be possible, in this way, to supply space ships with the power they need from the mighty robot solar power stations which move in definite orbits. True, the distances will have to be relatively small for this purpose.

Will it be possible, when on Earth, to see the artificial satellites created by man?

According to calculations, if small satellites, having a diameter of about a metre, are not very high above the Earth, it will be possible to see them not only in a telescope or spyglass, but when atmospheric conditions are favourable, even with the naked eye.

Satellites with a diameter of several tens of metres may be seen with the naked eye even if they are moving along a one-day orbit, that is, at an altitude of over 35,000 kilometres. The satellite will be best visible at twilight, before sunrise and after sunset, and will look like a little bright star rapidly moving through the dark sky, sparkling in the rays of the Sun, which is invisible to those on Earth.

A satellite at an altitude of 800 kilometres will traverse the sky in 15 minutes. By looking through binoculars we will be able to see the "suite" of this main satellite: an interplanetary community whirling around

in the sky, a huge laboratory of scientists and the station from which space ships take off.

And what a marvellous picture the terrestrial dwellers will see on holidays, when their distant brethren on the numerous artificial stars will light up the festive, glittering lights of their entire "space fleet"! Sparkling with numerous colours, shining with the lights of many-coloured searchlights which flare up and then go out, the artificial stars will traverse the evening sky in all directions and at various speeds. It will seem as if the mysterious space itself, the entire Universe, is saluting the people who have conquered the cosmos.

Part Four

"CONQUEST" OF THE UNIVERSE

Chapter 13

THE FIRST GOAL—THE MOON

> Man will not remain for ever on Earth, but, in his pursuit of light and space, will first timidly proceed beyond the boundaries of the atmosphere, and then will conquer all the space around the Sun.
>
> K. E. TSIOLKOVSKY

One need have no doubt whatever that the first goal to be selected by space ships will be the belle of the heavens, the Moon. And not because it has been lauded by the poets, nor because it has, since times immemorial, been the object of our fantasy. The selection of an itinerary for the first space flight is determined by much more prosaic considerations: the Moon is that celestial body which is closest to the Earth, and a flight to the Moon will be the simplest of all space flights.

The Moon moves around the Earth in an elliptical orbit which is almost a circle. The distance from the centre of the Earth to the apogee of the Moon's orbit, that is, to that point in its orbit which is at the greatest distance from the Earth, is equal to 407,000 kilometres, and the distance to its perigee, that is, to that point in the orbit of the Moon which is nearest to the Earth—approximately 356,000 kilometres. The mean distance between the centres of the Earth and the Moon is equal to approximately 384,000 km.* When the Moon is closest to the Earth, only 27 globes as big as the Earth could be placed on a straight line between the

* The diameter of the Sun is almost twice the diameter of the Moon's orbit, so that this orbit would be deep within the bowels of the Sun if the Earth were its centre.

two. A flight by plane along a straight line from the Earth to the Moon would be equivalent in distance to about nine round-the-world flights.

Judged on a cosmic scale, the distance from the Earth to the Moon is insignificant; it is hundreds of times less than the distance to other heavenly bodies, even those that are closest to the Earth. This is the determining factor in selecting the Moon as the first goal for a flight in space.

The less the distance from the Earth, the less the duration of the space flight, which, in turn, means less difficulties and dangers connected with such a flight. This is an especially important advantage in the beginning, when captains and pilots of space ships have not as yet adequately studied all the "reefs" and "submarine currents" of the ocean of space.

A second advantage resulting from the fact that the distance to the Moon is not so great, is not such an obvious one, but is actually of very great importance. A flight to the Moon is the only instance of a flight from the Earth when the distance of the space ship from the Sun will change so little during flight as to make this change negligible. But this also means that the attraction towards the Sun will exercise practically no influence whatever on the flight of the ship,* whereas such influence is decisive during more distant flights to the planets. This means, in particular, that any ship ready to fly to the Moon may start at practically any time, at any moment, without waiting for mutually favourable positions of the stations from which it leaves and for which it is heading, as would be necessary in case of a flight to the planets. This is also true as regards the return flight to the Earth. That is why, in the future, when space flights will have become an ordinary undertaking, an everyday affair, as airplane flights on terrestrial airlines are today, passenger ships travelling, let us say, from Moscow to the Moon, will have as regular a "train schedule" as the Moscow-Sochi express trains. Flights to Mars or Venus will be more like the passage of ships along the Northern Sea Route, in which an entire caravan of ships takes part, travelling during the most favourable season of the year.

Judging by usual terrestrial conceptions, it might seem, at first glance, that there is another very important, if not decisive, advantage as a result of the relatively small distance a space ship will have to cover in

* The change in the force of attraction towards the Sun during the Earth-Moon flight will be less than one per cent; it should be taken into consideration only when calculations are most exact.

its flight to the Moon, a distance that is hundreds of times less than that of any other space flight. This advantage is that much less fuel will have to be expended. It may also seem that the need of expending large amounts of fuel makes only relatively short flights possible today, such as a flight to the Moon, and that more distant flights to the planets are as yet out of the question.

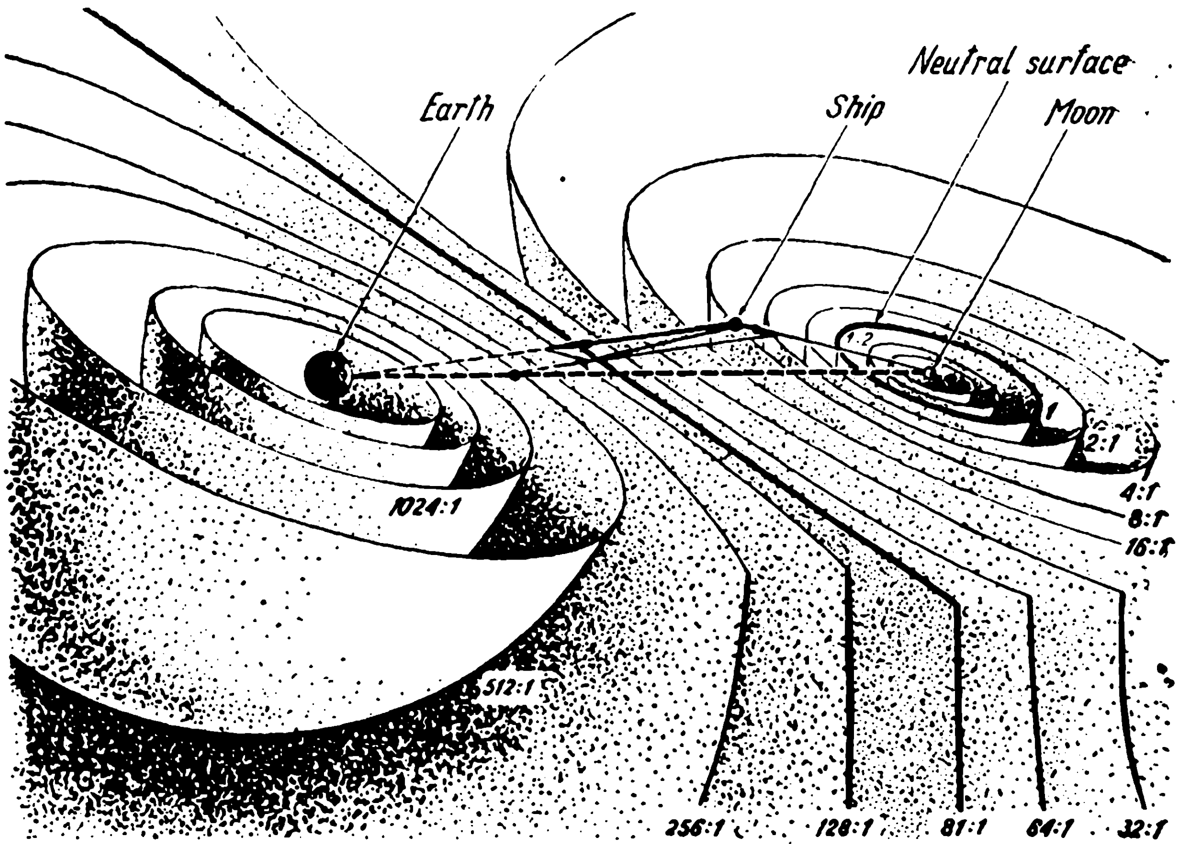
However, such an impression would be erroneous. During any terrestrial journey, it is true, whether on land, on water or by air, the greater the distance we have to travel, the greater will be the amount of fuel expended, for the engine of the automobile, the ship or the plane will have to operate throughout the entire trip. However, the situation is quite different as regards space travel. Here a flight that is many times greater in distance will require much less fuel. This is one of the unique features of a flight in space. During a space flight the ship's engine operates, consuming fuel, only an insignificant part of the total time it takes to make the flight. The rest of the time the engine is shut down, and the ship flies on the kinetic energy accumulated while the engine was operating. That is exactly what chauffeurs do when they first drive their cars at a great speed, then shut off the motor and continue to coast, using the speed it has acquired. However, during a space flight the ship "coasts" in this fashion only once or twice, at the beginning of the trip and when it becomes necessary to change the direction or speed of the ship's motion.

The consumption of fuel during a space flight is, therefore, determined not by the distance to be covered, but by other factors, chiefly by the fields of attraction the ship must overcome during its flight, and this, in turn, means it is determined by the mass of the celestial body towards which the ship is flying. Judged from this viewpoint the Moon is far from being an ideal goal because of its relatively large mass. It is not surprising that a trip to the Moon will require a greater expenditure of fuel than certain other space flights over distances tens and hundreds of times greater, as, for instance, flights to many asteroids.

The Moon is quite an original heavenly body, quite exceptional in the family of satellites of planets that make up the solar system, a family that has 30 known members* besides the Moon. This originality of the

* Of these, Neptune's second satellite, Nereid, was discovered only in 1949, and Jupiter's twelfth satellite in 1951. It is possible that there are other satellites which have not as yet been discovered.

Moon lies in the fact that it is a gigantic satellite, one which, for its dimensions and mass, is more like its planet, the Earth, than any other satellite.* The diameter of the Moon is about $^4/_{15}$ the diameter of the Earth, and is equal to 3,476 kilometres. In this respect the Moon takes



In the field of gravitation of the Earth and the Moon. Surfaces are shown, on any point of which the ratio of the forces of attraction to the Earth and the Moon is identical (indicated by figures).

precedence over the other satellites. Neptune's satellite, Triton, is less than $^1/_{10}$** the diameter of its planet; Uranus' first satellite, Titania, is about $^1/_{30}$ as large as its planet, while the satellites of Mars, Jupiter and Saturn are only hundredths the size of their planets. The ratio as regards the masses of the satellites is about the same. The Moon's mass is about $^1/_{81.5}$ that of the Earth; Triton's mass is $^1/_{290}$ that of Nep-

* Judged by their absolute value Neptune's satellite Triton, Saturn's satellite Titan and Jupiter's satellites Io, Ganymede and Callisto are greater than the Moon.

** Triton's diameter has not been definitely established as yet.

tune's, and the masses of Jupiter's and Saturn's satellites are tens and hundreds of thousands of times less than those of their planets.

We can, of course, be proud of that exceptional couple, the Earth and the Moon, and of the rare beauty of the picture they will offer future space travellers when the latter observe this "double star" from their cosmic ship, somewhere en route from the Earth to Venus. However, from the viewpoint of astronautics, we cannot help but regret that the Earth is so large and that we do not live, for instance, on Mars, whose mass is $^{1}/_{10}$ that of the Earth's. For the very same reason we cannot help but regret that the Moon is so great, and that we do not have a minute satellite close by, one like the Martian satellites, Phobos and Deimos, whose diameters are only 15 and 8 kilometres, and which are only 9,380 and 23,500 kilometres from Mars. If we lived on Mars, to say nothing of Mercury, it is quite possible that space ships would already be ploughing the boundless expanses of space; the escape velocity from Mars, which is only 5 kilometres per second, could easily be attained by modern jet technique. If the Earth were to change satellites with Mars, we would have remarkable space bases, and there would be no need of erecting small artificial "moons" simply because the real Moon was "bad" from the point of view of astronautics.

Neither the large mass of the Moon, the cause of its own field of attraction (which must be taken into serious consideration), nor the relatively large distance of the Moon from the Earth are to the liking of the astronaut.

The Moon's field of gravitation is superimposed on the terrestrial. If the motor of the space ship is shut down and there is no air resistance (or we may ignore it), and if the flight is so close to the Earth that we need consider only the Earth's attraction, then only one force of gravity, that directed towards the centre of the Earth, will influence the ship.* The closer the ship approaches the Moon, the greater will be its attraction towards the Moon, until we are finally compelled to take it into consideration. There are now two forces that influence the ship: one directed towards the centre of the Earth, the other—towards the centre of the Moon. A resultant force must be found, obviously, according to the rules

* Of course, the force of attraction towards the Sun also influences it, but we may ignore that for the time being.

governing a parallelogram; it will no longer be directed towards the centre of the Earth, but to some point between the Earth and the Moon.*

Finally, the ship, in its flight to the Moon, no matter what path it travelled, would inevitably reach such a point where both forces of attraction, that of the Earth and that of the Moon, would be equal. Of course this point will be much closer to the Moon than to the Earth, for the Earth's mass is greater. Inasmuch as the force of attraction is inversely proportional to the square of the distance, and the ratio of the masses of the Earth and the Moon is approximately equal to 81, it is obvious that both forces will become equal when the distances of the ship to the centres of the Earth and the Moon, will be to each other as $\sqrt{81} : 1$, that is, when the distance to the centre of the Earth will be approximately 9 times greater than the distance to the centre of the Moon.

Apparently there are a countless number of such points in the space between the Earth and the Moon, which meet this condition, so that these points form an entire surface. This surface possesses a remarkable property. It is a unique sort of boundary: on one side of this surface the ship will fall to the Earth, and on the other side—to the Moon.

There is one point in this surface which is of special interest, that which lies on a straight line connecting the centres of the Earth and the Moon. This point is at a distance of only 38,000 kilometres from the centre of the Moon. Obviously there are no forces at all which affect the ship at this point: two forces that are equal and are directed in opposite directions do not produce any resultant. In other words, a ship which does not possess its own velocity should, theoretically, remain at this point, which is called the critical or neutral point, an endlessly long time. At this critical point, the weight of a body is equal to zero, not because it no longer presses against its support, which falls freely together with it, as is the case on an artificial satellite, but because the force of attraction really does not affect it.

The traveller who decided to make his way to the Moon up a ladder, as we used to read about in fairy-tales, would rise upwards going head first, until he reached the critical point; there he could rest without using the ladder, and then he would have to turn around with his head towards

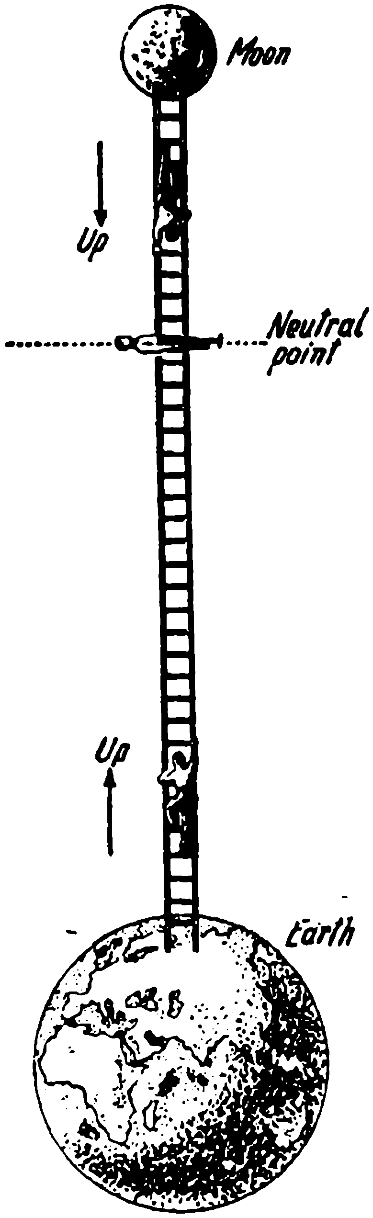
* So long as the force of attraction towards the Earth is greater than that towards the Moon, the ship, if it were immobile, would nevertheless fall on the Earth.

the Earth: for him, now, "below" would be the Moon.*

The chief question that arises when organizing any space flight, including a flight to the Moon, is the amount of fuel that will have to be expended. As we have already pointed out above, this determines the question of whether or not the given flight is at all possible, and what the space ship should be like.

As regards the simplest cosmic flights near the Earth, flights of orbital rockets, for instance, this problem is solved relatively simply, as we have seen in the preceding chapter.

If the Moon did not have its own field of attraction, a flight to the Moon would be an ordinary flight, but to a greater altitude, one corresponding to the distance of the Moon from the Earth. In order to reach any point in the lunar orbit, the ship, when escaping from the Earth, must be imparted such an initial velocity, that its velocity at the given point in the lunar orbit will be equal to zero. Obviously this velocity is slightly less than the escape velocity, at which the ship's velocity becomes equal to zero only in infinity, as we know. At first glance it may seem that this difference should be considerable, for the path from the lunar orbit to infinity is so great. However, in actual fact such is not the case, the difference being less than one per cent.



"Travel" from the Earth to the Moon.

* This is, of course, a very simplified presentation of the case, for we have ignored the attraction of the Sun and the revolution of the Moon around the Earth. As a matter of fact, the attraction of the Sun, which is twice the attraction of the Earth and the Moon, will affect a ship at such a critical point, and the ship will not remain at this point but will begin falling towards the Sun. The result will be that the ship will move away from the critical point and fall either on the Earth or on the Moon, depending on their position in relation to the Sun.

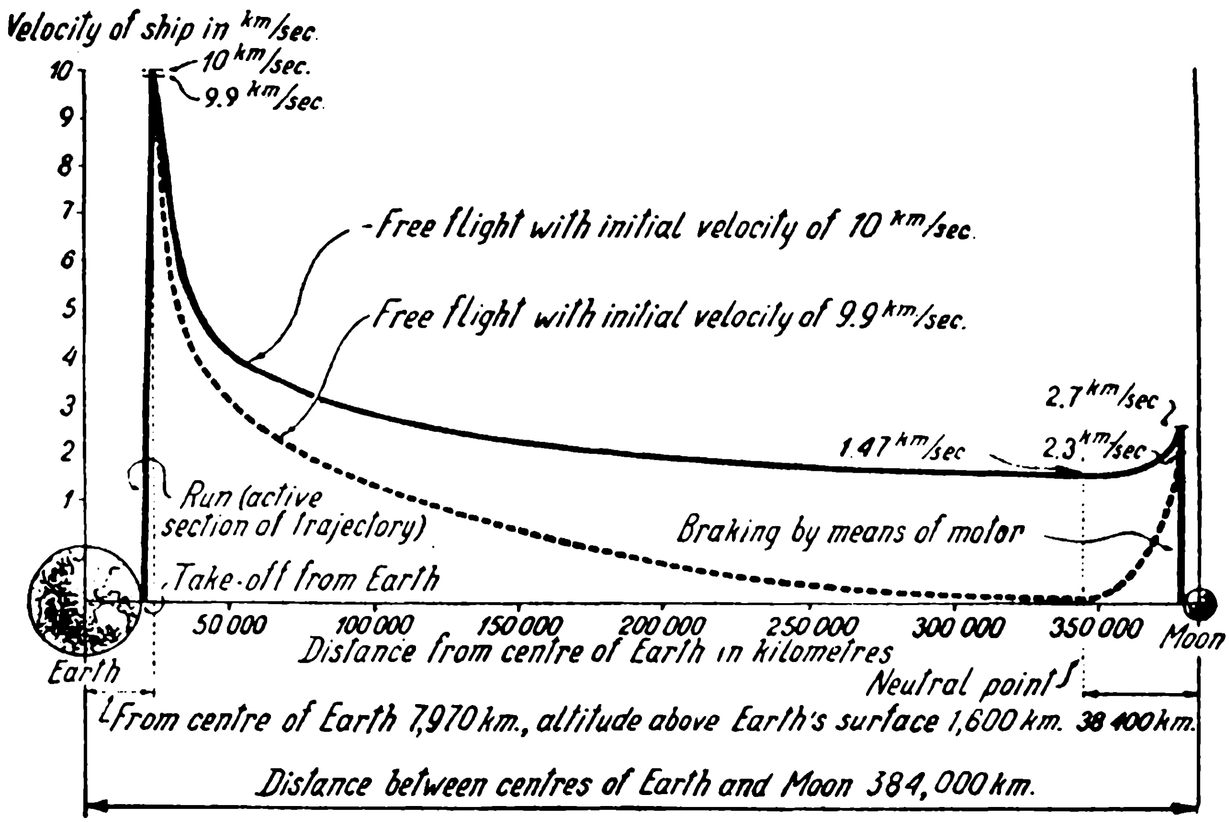
The attraction towards the Moon changes the situation, and favourably so, if only the nature of the meeting between the rocket and the surface of the Moon is of no significance, as will be the case, for instance, with the first robot rockets, which will simply have to inform of their collision with the Moon by, let us say, a bright flash or a column of smoke.

The favourable effect of the attraction towards the Moon in this case is twofold. First of all, by means of the velocity acquired during its take-off from the Earth the rocket should reach not the lunar orbit, but that neutral surface between the Earth and the Moon, where the attraction to these two bodies becomes equal. The further motion of the rocket towards the Moon will result from the Moon's attraction—the rocket will simply fall on the Moon. True, when that does happen, the rocket's speed at the moment of impact with the surface of the Moon will be about $2^1/_3$ kilometres per second; it will be greater than the speed of an artillery projectile that comes flying out of the barrel of a gun of the greatest range. Such a landing on the Moon by the rocket will most likely resemble a point-blank shot at the Moon. However, as we have already agreed, we won't let that disturb us. As the altitude to which the push from the Earth will now send the rocket is about 40,000 kilometres less, the initial rocket speed should also be less. Forty thousand kilometres is about one-tenth of the entire path, but the Earth's field of attraction weakens rapidly with the distance, and that is why the decrease in the initial velocity of the rocket, as a result of these 40,000 kilometres, proves to be insignificant; it is less than 0.1 per cent.

Another favourable effect of the Moon's field of attraction is that since it is superimposed upon the terrestrial field, the latter is weakened, and the force with which the rocket is drawn to the Earth in its flight from the Earth to the neutral surface is thus lessened. This, in turn, reduces the necessary initial rocket speed, but again to a very slight degree, about 0.2 per cent. Thus the positive effect of the attraction towards the Moon is not very great and may be ignored. On the other hand, the difficulties occasioned by this attraction in those cases when a smooth landing of a space ship on the Moon must be ensured, are much greater. If the ship is not to be smashed up when landing, it must brake in such a way that at the moment it meets the Moon's surface, its velocity will be equal to zero. In this case not even that slight speed with which a plane lands at an aerodrome is permissible, for there are no landing sites on the Moon.

Inasmuch as the Moon has no atmosphere, the ship will have to slow down by using its own motor. In order to do this the ship will either have to make a 180° turn, with its stern to the Moon, or special motors for braking will have to be installed on it in front. In any case, the jet thrust of the engine must be directed opposite to the direction of the flight, decreasing its velocity gradually. When braking in this manner, the expenditure of fuel will not be less than that necessary to impart to the ship the escape velocity from the Moon and will be equal to about $2^{1}/_{3}$ kilometres per second. Actually, it will be greater, for in this case the ship and the Moon, when meeting, will have different velocities, and this difference in velocities must be reduced by the motor.

If we are planning a flight to the Moon with a return to the Earth, the influence of the Moon's field of gravitation will be felt a second time, when escaping from it. Once more it will be necessary to impart a velocity of $2^{1}/_{3}$ kilometres per second to the ship, in order for it to reach the point from which it will begin its fall to the Earth.



Graph of flight: Earth-Moon.

We can now approximately estimate the full value of the ideal velocity which should determine the minimum supply of fuel on a space ship making a flight to the Moon and back:

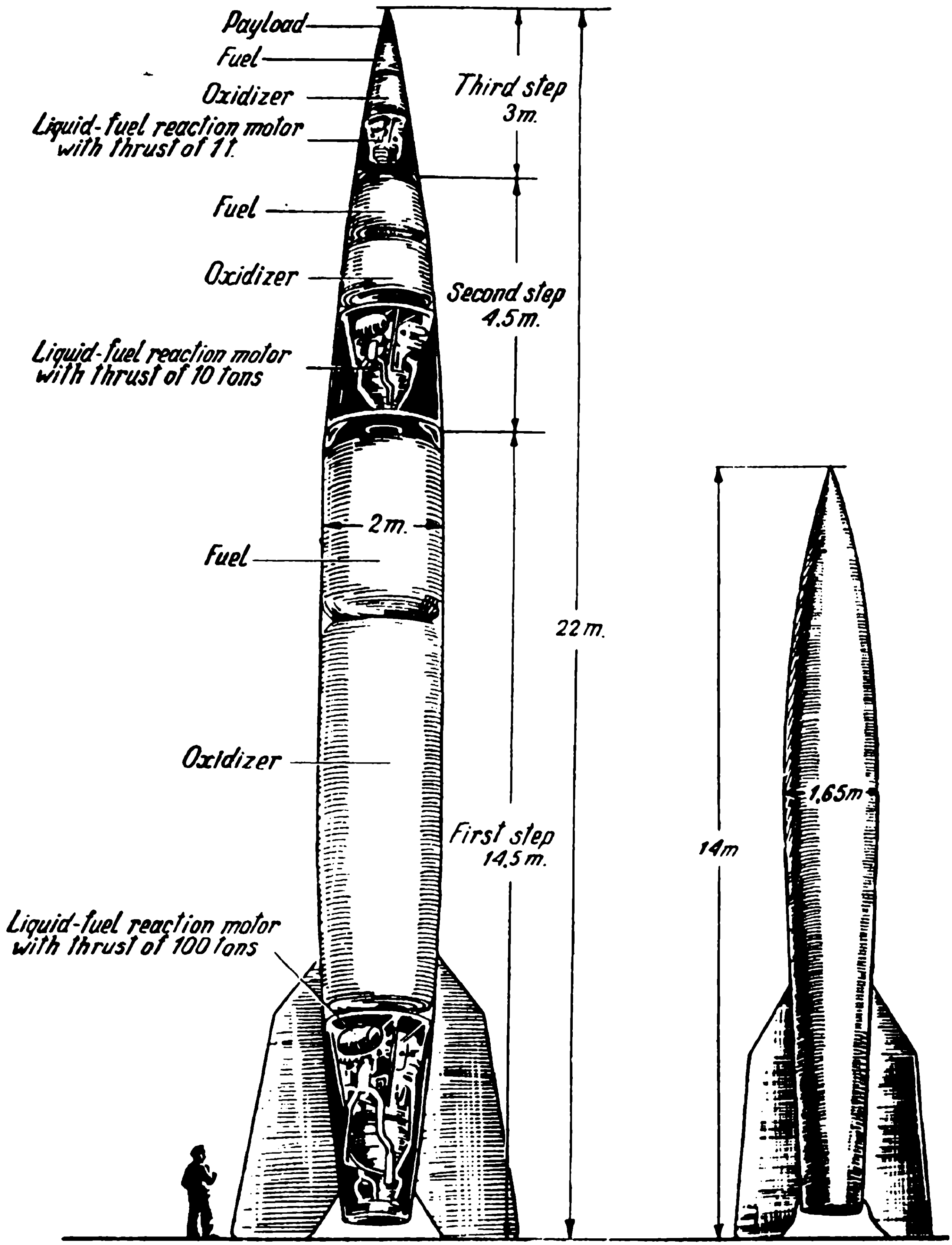
Initial velocity at take-off from the Earth	11.5 km./sec.
Braking when landing on the Moon	2.3 » »
Take-off from the Moon	2.3 » »
	Total 16.1 km./sec.

However, the actual supply of fuel will have to be much greater than this minimum.

First of all, the ship's velocity at the neutral point should not be equal to zero. Of course, if this velocity is equal to zero, the consumption of fuel will be a minimum, but the duration of the flight will increase inordinately. For instance, if the ship's velocity at an altitude of 1,600 kilometres is equal to 9.9 kilometres per second, the ship will cross the neutral point at a velocity close to zero.* If the take-off velocity is increased by only 100 metres per second, that is, if the velocity is raised to 10 kilometres per second, the ship's velocity at the neutral point will be equal to about 1.4 kilometres per second, and the total duration of the flight will be reduced to one half, that is, from 100 to 50 hours. It is most likely that the ship will cross the neutral point at a speed of about one kilometre per second. But this means that the initial velocity of the ship during the take-off from the Earth, the expenditure of power to brake when landing on the Moon, and the initial velocity during the take-off from the Moon will have to be increased. In this case the total increase in the ideal velocity can be estimated at about 1.5 kilometres per second. If we also take into consideration the inevitable losses in velocity during the flight and also the necessary reserve supply of fuel on the ship to compensate for mistakes in steering, etc., we get a value of not less than 20 kilometres per second for the ideal velocity.**

* In the figure on p. *137*, for purposes of simplicity, the flight is considered as taking place along a straight line joining the centres of the Earth and the Moon (as in the figure on p. *135*), and the motion of the Moon in its orbit is not taken into consideration.

** A more cautious estimate which takes into consideration, for example, braking by the engine when landing on Earth, gives an even greater value for the ideal velocity, one equal to about 25 kilometres per second. Sometimes even greater values are given, as 30-32 kilometres per second.



Three-step rocket for sending a load of 10 kg. to the Moon.
At right—long-range rocket described in Chapter 6.

According to Tsiolkovsky's formula, when the jet velocity of the motor is three kilometres per second, the value of the ratio of the initial and final masses of the ship will be about 800. This proportion is unattainable in practice, and it is, therefore, impossible, at the present level of development of jet technique, to make such a flight to the Moon. An increase in the jet velocity to four kilometres per second, which will be fully possible in the future, would decrease the necessary ratio of the masses to 150, which can be attained, in principle, by means of a multi-step train, but its weight at the take-off from the Earth, even with an insignificant pay-load, would be tens of thousands of tons, that is, it would be equal to the weight of gigantic ocean liners. Such is the disastrous influence of the massiveness of the Earth's satellite, if we wish to make a landing on it. That is why we can hardly expect to "conquer" the Moon by means of a frontal attack on it. A well-planned siege and careful preparation for a decisive attack would be more effective here.

The first rocket to be sent to the Moon will very likely be one whose aim will be simply to signal its safe arrival, and for this purpose several kilogrammes of powder on the rocket* will be sufficient. Such a rocket could be sent to the Moon even today. According to one project, for instance, such a rocket with a pay-load of 10 kilogrammes should weigh 50 tons at the take-off. This three-step rocket will not be much larger than the long-range rocket described in Chapter 6 (for purposes of comparison these rockets are shown in the figure on p. *139*).

The next vehicle to be sent to the Moon will be a robot radio station with a number of measuring instruments. This station will relay its lunar "impressions." Then, perhaps, a television broadcasting station will be added to it, and we will be able to see the surface of the Moon close by. Before a flight to the Moon is undertaken, it will undoubtedly be preceded by a flight around the Moon in a space ship at a relatively small distance from it, first without people and then with people. Such a flight would be of importance for various reasons, one of them being that we

* In order to exclude all possibility of "overlooking" the moment when the rocket collides with the Moon, as may be the case because of clouds, and also in order to create a permanent indication of the place where the rocket falls, it will be feasible to supply the rocket, in addition to the powder, with a charge of plaster of Paris or crushed glass. The white spot that would thus be formed on the dark surface of the Moon would always be visible from the Earth.

would at last be able to glance at the "back" part of the Moon, which we never see from the Earth. Such a flight will require only a little more power than is needed for a simple flight to the lunar orbit. The necessary ideal velocity would be 13-14 kilometres per second, which, at the modern jet velocity of about three kilometres per second, could be attained by a five- or six-step rocket.

Such a flight to the Moon clearly illustrates the importance of artificial terrestrial satellites for interplanetary communication if these satellites are to be used as refuelling stations for space ships.

Let us assume that such a refuelling station has been built at an altitude of 500 kilometres above the Earth, where it will keep whirling around the Earth along a circular or slightly elliptical orbit at a speed of 7.6-7.7 kilometres per second. Hundreds, thousands of tons of fuel can be gradually transferred from the Earth by means of freight rocket "tankers" and accumulated in the cisterns of this fuel station.

The Moscow-Moon space ship will fly over to the refuelling station and regulate its velocity to equal that of this artificial satellite. Both of them will then go whirling around the Earth side by side. Much experience has been acquired in refuelling jet-propelled airplanes in the air with fuel from flying "tankers," heavy and slower-moving aircraft, and this experience can be of great help in developing the technique of refuelling in space. There have already been cases when small, rapid, jet-propelled planes that were making long-range flights, refilled their tanks in the air. All they had to do was to decrease their flight velocity to that of the "tanker" and then continue on their way.

As was already pointed out in the preceding chapter, in order to fly to such a refuelling station a space ship should have an ideal velocity of 10-12 kilometres per second. After refuelling, it will be necessary to turn on the ship's motor once more, in order to increase the velocity from the circular to the escape velocity. To do this it will be necessary to take advantage of the most favourable position of the satellite in its orbit.* The velocity of escape from the satellite will be less than that from the Earth; in the given case it can be considered as equal to 11 kilometres per second. To increase the ship's velocity from the circular of 7.6 kilometres per

* This question, as others connected with the trajectories of the flight of space ships, will be discussed in greater detail in Chapter 15.

second to the escape velocity of 11 kilometres per second, an additional velocity of 3.4 kilometres per second will be necessary. In this case the ideal velocity of the ship whose fuel supply has to be calculated, will be decreased to 8.1 kilometres per second, as a velocity of 3.4 kilometres per second will now be required instead of the 11.5 kilometres per second necessary during a take-off directly from the Earth. It follows that the ideal velocity will now be equal to about 12 kilometres per second, and not 20. If the jet velocity is three kilometres per second, the necessary mass ratio of the ship will decrease correspondingly, from 800, as it was before, to 40-50. We thus see that refuelling en route will not only make it possible to lessen the required amount of fuel on the ship, but will also make the given flight actually possible.

Another flight to the Moon can be undertaken with refuelling in the air, even though special artificial satellite fuel stations have not as yet been created. Instead of one ship of 20,000 tons taking off, three rockets, each weighing 600 tons, can fly off simultaneously. At an altitude of 500 kilometres the rockets become satellites of the Earth. Two of these refuel the third, which then continues its journey. At a small distance from the Moon this ship leaves its reserve fuel tanks flying about in its orbit, where, for some time, they are satellites of the Moon, while the ship itself makes a landing on the Moon. On the return trip it "picks up" the tanks. These operations involve the least waste of fuel on the take-off run and braking of the fuel itself, which causes most trouble in astronautics.

The duration of the flight to the Moon will depend on the route selected and, mainly, on the flight speed. As when travelling on Earth, the quicker the flight to the Moon, the more expensive it will be, for it will require a greater expenditure of fuel.

The lowest velocity the ship should have at the Earth, if it is to reach the Moon, is 11.1 kilometres per second. If the velocity is 11.2 kilometres per second, it will fly off into infinity, for this is the escape velocity. Therefore, all orbits of the ship which intends to fly around the Moon require an initial velocity between 11.1 and 11.2 kilometres per second. At the minimum velocity of 11.1 kilometres per second the ship will fly to the Moon in about 115 hours. In other words, this is the maximum possible duration of such a flight. At a velocity of 11.2 kilometres per second the flight will last about 50 hours. If the velocity is increased still more, the duration of the flight will be greatly decreased.

At an initial velocity of 15.2 kilometres per second, it will last 10 hours, and if the velocity is 21.2 kilometres per second the flight will take 6 hours. Thus, if the initial velocity is doubled, the duration of the flight is decreased to $^1/_{20}$. This is a feature obviously characteristic of astronautics, for such a phenomenon is not observable on Earth.

A Moscow-Moon express will make its flight in 24 hours or even in one night, as the Moscow-Leningrad trains now do. The organization of such express flights will become possible only when fuels with a greater calorific value are found, and even then, when refuelling takes place en route. Such flights will probably take two or three days. Throughout the flight the ship's motor will work no more than 10 minutes, during its take-off from the Earth and when landing on the Moon. The rest of the journey the ship will fly without consuming a drop of fuel. Unless this were so, we could not even dream of a space flight of any kind whatsoever.

Chapter 14

A FLIGHT TO THE PLANETS

The Earth has only one satellite and so, whether you wish it or not, the space flight following the one to the Moon will have to be to some planet, one of the other eight planets of the solar system.

One would imagine that the Earth's two neighbouring planets in the space around the Sun, Venus and Mars, would be selected for this honour. However, there are other goals much easier to attain, and not merely because they are closer to the Earth than these two planets. They are certain minor planets of the solar system, the so-called asteroids.

A hundred and fifty years ago, on the first day of the past century, the first and largest of these asteroids was discovered, Ceres. Today we know of more than 1,500 of these asteroids, and new ones* are being discovered all the time. Many of these have been discovered by Soviet astronomers and include the asteroids "Russia," "Moscow," "Simeis," "Armenia," "Komsomolia" and others.

According to a hypothesis advanced by some scientists, the asteroids are fragments of a planet that once revolved around the Sun in an orbit

* Over 6,000 asteroids have already been discovered, but only 1,600 have been entered in the catalogue, as their orbits must first be calculated before this is done.

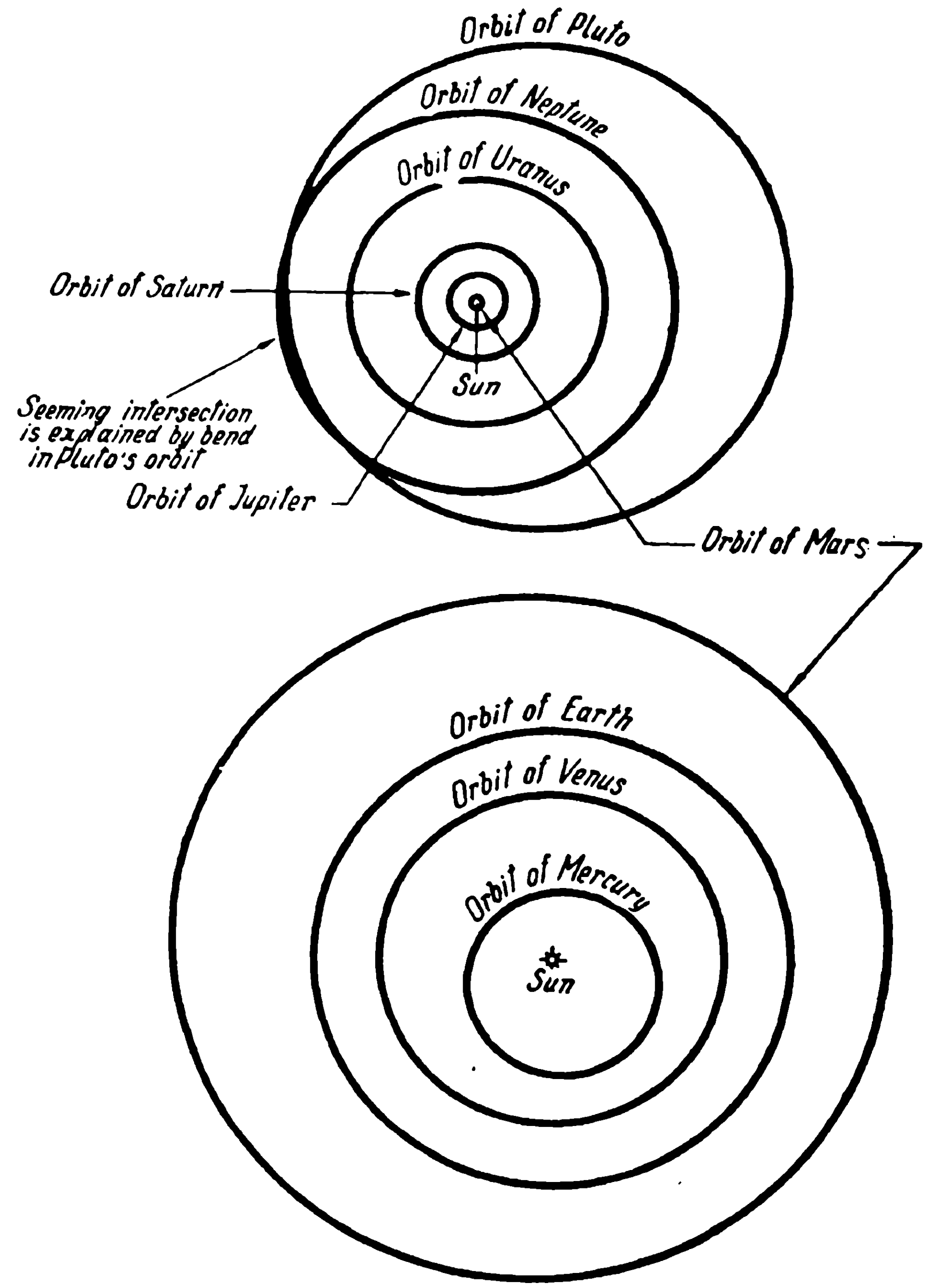
lying between the orbits of Mars and Jupiter, but which has since been destroyed.* Whatever the case may be, these little planets revolve around the Sun just as their bigger sisters do, but in elliptical orbits that are usually much more elongated. Certain asteroids at their aphelion, that is, at the point in their orbit which is most distant from the Sun, closely approach Jupiter's orbit and even Saturn's, while at their perihelion, that is, at the point nearest to the Sun, they come within the orbits of the Earth, Venus and even Mercury. Those asteroids whose orbits approach the Earth's orbit may prove interesting as the next goals for space flights.**

The family of asteroids which "touch the Earth" is by no means a small one. The best known of these is Eros, which has done science a good turn, for with its help astronomers have been able to determine, with greater precision, the distance of the Earth from the Sun. Eros was first discovered in 1898. It is apparently not spherical in form, but irregular. The diameter of this little planet, or, to be more exact, its largest dimension, is about 25 kilometres. Eros can be seen in a telescope of average magnitude. The shortest distance from Eros to the Earth is $^2/_5$ of the shortest distance from the Earth to Mars, and is equal to approximately 22.5 million kilometres. In January 1931, the last time that Eros approached the Earth, its distance from the Earth was 26 million kilometres. It will next approach our planet in 1975.

The asteroid Albert was discovered in 1911; its diameter is only about four kilometres, and it approaches the Earth at a distance of 28 million kilometres.

* This viewpoint was expressed by the Soviet scientists S. Orlov, A. Zavaritsky and others. Orlov named this planet "Phaethon," after the mythical son of the ancient Greek god of Sun, Helios, who perished when he couldn't control the fiery horses with which he tried to traverse the heavens in his father's chariot. Another hypothesis is that the asteroids may be fragments of comets.

** Tsiolkovsky expressed this idea. Certain asteroids may be used to make "excursions" in the solar system. For instance, the asteroid Hidalgo, discovered in 1920, then lost and rediscovered in 1934 by the Soviet astronomer G. Neuimin, may serve this purpose. Hidalgo has a greater orbit than any other asteroid. At its aphelion it is ten times farther from the Sun than the Earth is (it almost reaches Saturn's orbit), while at its perihelion it approaches Mars' orbit and is only 1½ times farther from the Sun than our planet, the Earth. It takes Hidalgo 14 years to make a trip in its entire orbit.



Above is shown the scheme of the solar system on scale where 1 mm. is equal to one astronomical unit (astronomical unit—distance from the Earth to the Sun—is equal to 149.5 million kilometres). Using this scale, we can show the orbits of only the five so-called outer planets, beginning with Jupiter. Below we show, on an enlarged scale, the scheme of the central part of the solar system with the orbits of the inner planets. The increase in scale is seen from the orbit of Mars, as given in both schemes.

Two interesting asteroids were discovered in 1932. One of them, Amour, which has a diameter of not more than three kilometres, at that time came as close to the Earth as 15 million kilometres. It was seen again in 1940. Astronomers, in their "pursuit" of such minute celestial bodies, come up against some very difficult tasks. Their paths are hard to calculate with precision because of the various perturbations to which they are subjected as a result of their small mass. Thus, asteroids that have already been discovered often "get lost" and have to be discovered anew. The other of the two asteroids mentioned above is Apollo, which came even closer to the Earth, a little over 11 million kilometres from it. So far this asteroid has never been seen again. Its diameter is about two kilometres.*

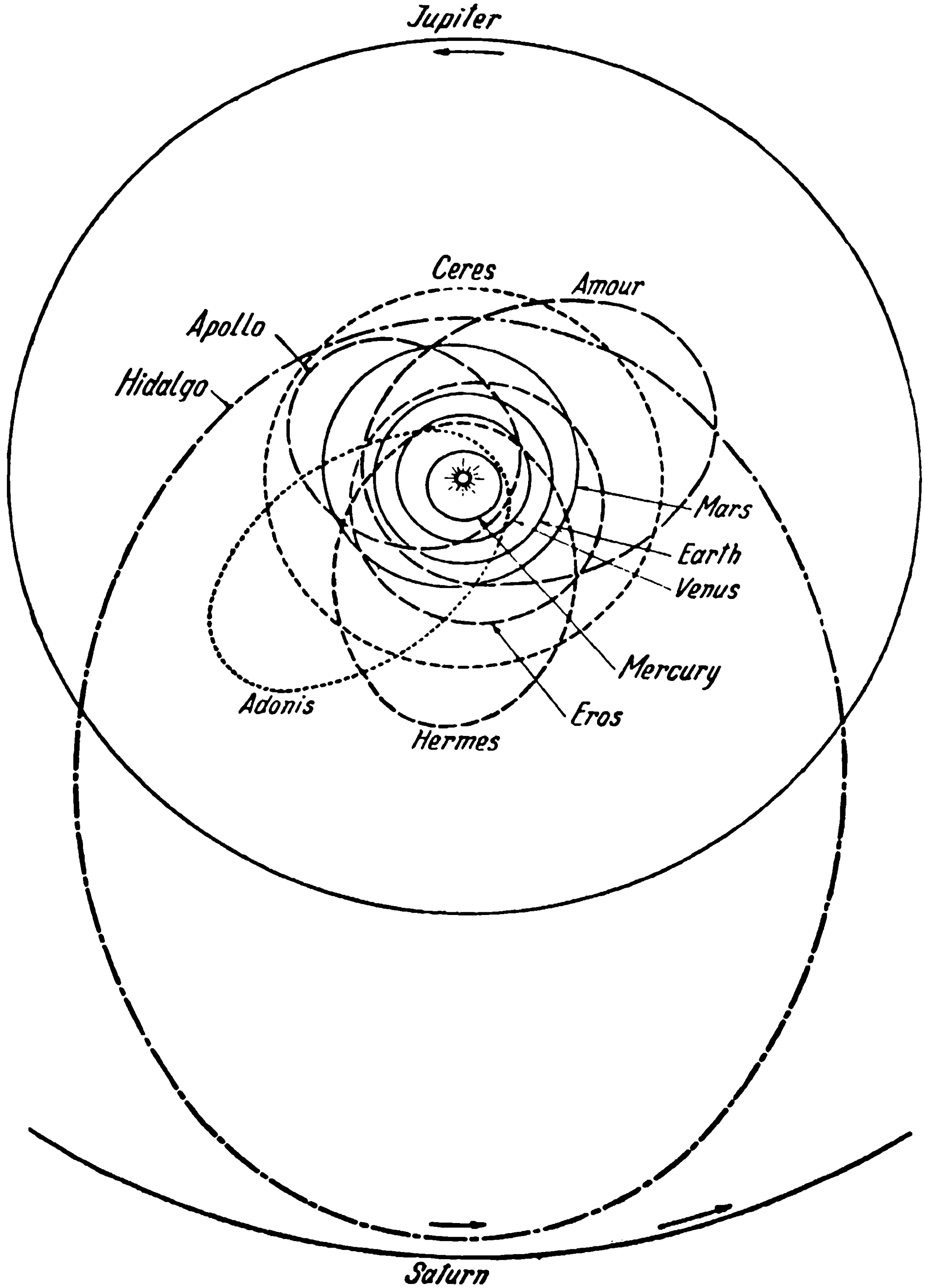
Another asteroid, Adonis, was discovered in 1936. It is even smaller than Apollo, its diameter being only one kilometre. Adonis passed the Earth at a distance of only 1.5 million kilometres.

However, the asteroid Hermes set the record in this respect. Hermes, whose diameter is slightly over 1.5 kilometres and whose mass is equal to 3,000 million tons, is only a grain of sand when judged on a cosmic scale. In 1937 Hermes approached the Earth at a distance of 780,000 kilometres, which is only twice as far as the Moon is from the Earth. According to calculations, when it is in opposition it may come as close to the Earth as 500,000 kilometres.

A most interesting asteroid, Icarus, was discovered in June 1949. It is not by chance that it received its name. Like Daedalus' mythical son, this asteroid "flies" too close to the Sun. Icarus' orbit is very elongated, and is very much like a comet's. At its perihelion it is 30 million kilometres from the Sun, that is, it comes within the orbit of that planet which lies closest to the Sun—Mercury. The hypothesis exists that at this time the Sun's rays heat Icarus to such an extent that it becomes luminous itself.

One of the latest asteroids that "touch the Earth" was discovered in 1950. It passed the Earth at a distance of about nine million kilometres. There is no doubt that in the future new asteroids will be discovered,

* Apollo passed Venus at a distance of only 200,000 kilometres, which is a record for its small extent. Its distance from Venus was only half of the distance of the Moon from the Earth.



Orbits of certain asteroids.

which will come close to the Earth.* Astronomers expect to discover many thousands of such asteroids and, of course, among them will be some that will "touch the Earth."

Flights to certain "nearby" asteroids require the least expenditure of fuel when compared to flights to any other heavenly bodies, even if these asteroids are tens of times farther from the Earth than the Moon is, so important is the absence of any considerable field of attraction near these minute asteroids. It is only necessary to select such asteroids whose own velocity is not too great.

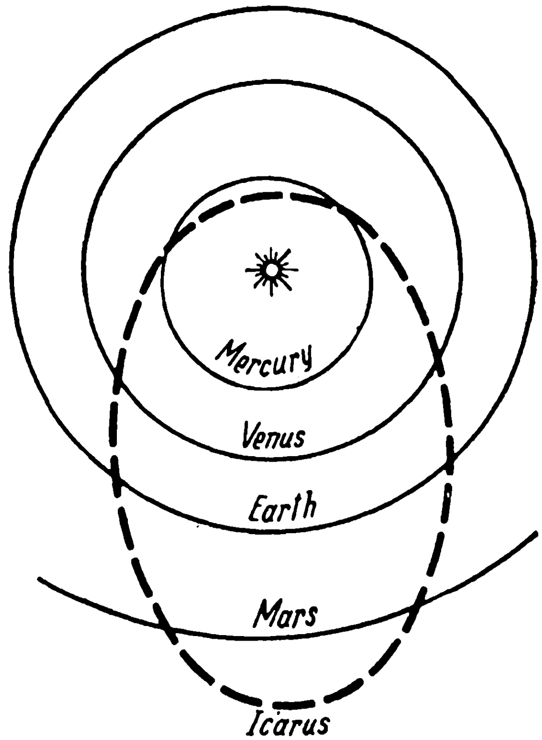
Of the Earth's two neighbours, Venus and Mars, it is easier to reach Mars, as we shall see later on, although the distance to it is greater than the distance to Venus. This is due to the fact that Venus has a considerably greater mass; the shortest distance from the Earth to Venus is 40 million kilometres, and to Mars—56 million. There is no doubt whatever, that in the future flights will be made to both of these planets, but only after a flight to the Moon and, perhaps, to some of the asteroids. These will be flights of the second stage. We shall speak of them in greater detail in the next chapter.

Flights to goals of the third stage will involve considerably greater difficulties. This group includes that planet of the solar system which is closest to the Sun—Mercury, whose average distance from the Sun is only 58 million kilometres, that is, about $^1/_3$ of the distance from the Earth to the Sun, and also those outer planets: Jupiter, which is 778 million kilometres from the Sun (5.2 times farther than the Earth), Saturn, which is about 9.5 times farther from the Sun than the Earth (1,428 million kilometres), Uranus, almost 20 times farther from the Sun than the Earth is (2,870 million kilometres), and the last two planets of the solar system, Neptune and Pluto, which are 30 and 40 times farther from the Sun than the Earth is (4,500 and 5,900 million kilometres).

The direct goal of a space flight may be, and most assuredly will be, the satellites of the planets, at least, certain ones of them. All told there are, as we have already pointed out, 30 such satellites in the solar sys-

* In 1948 and 1949 four asteroids were discovered, which came so close to the Earth that they left traces on photo-plates, similar to those of a meteor. These asteroids are so small that they cannot be seen even with the most powerful telescopes and can be discovered only when they pass close to the Earth. We may assume that there are many such minute asteroids moving right close to the Earth's orbit.

tem, not counting the Moon. Jupiter has the lion's share, having 12 satellites. Saturn takes second place, with nine satellites;* Uranus has five, Mars two, and Neptune two.



Orbit of asteroid Icarus.

The next stage, the fourth, will include flights to those heavenly bodies lying outside the solar system, to other worlds of stars. These flights will present immeasurably greater difficulties. It is sufficient to recall that the star lying closest to the Sun (from which it derives its name, Proxima**) belongs to the constellation of Centaurus, and is at a distance of 4.27 light-years from us, that is, at such a distance as takes a ray of light 4.27 years to traverse. There is no need to give this distance in kilometres, especially when we realize that a ray of light travels about 300,000 kilometres per second. That figure is equal to 4 plus 13 naughts after it. As it takes eight minutes for a solar ray to reach our eye, Proxima is about 280,000 times farther away from us than the Sun. The most distant worlds of stars that have been photographed by means of powerful telescopes are even millions of times farther away.***

Yes indeed, when we bear all these things in mind, it is obvious that a flight to the stars will not take place very soon.... Yet how interesting and important it would be for science! It would become possible to visit such places in the Universe where the mysterious processes of the birth

* Saturn is supposed to have a tenth satellite, which has even been named Themis. However, there is some doubt as to its actual existence.

** This so-called Proxima (from the Latin meaning "nearest") Centauri, a small reddish star, is to be seen alongside the bright star Alpha Centauri, which, before the discovery of Proxima, was considered the nearest to the Earth (Proxima is one per cent closer).

*** The most distant stellar worlds seen in the telescope are at a distance of about 1,000 million light-years.

of stars were taking place, in other words, we would be able to transfer ourselves to the epoch when the Sun was a mere infant. We would be able to visit the places where new planetary systems were coming into existence, just as our own solar system did several thousand million years ago.

When considered from the viewpoint of the duration of a human life, how infinitely slow is the development of the Universe, the solar system, our Earth! And how tremendously enriched would science be after an interstellar excursion, during which all the new secrets of nature would be revealed before our very eyes, and the different stages in the development of the Universe would unfold impetuously, one after another!

If flights to the stars were possible, we would be able to visit such distant worlds where life has been in existence and thinking beings have been living from times of old.

Science is of the opinion that an average of at least one out of every thousand stars has satellites, planets similar to our Earth. Inasmuch as there are about 100,000 million stars in that island Universe, the galaxy to which the Sun belongs, our galaxy must contain about 100 million "solar systems."

As yet even the most powerful telescopes do not permit us to see these planets of "alien" suns, but science has already advanced from hypothesis to direct proof. Such are the victories won by the "astronomy of the invisible" in recent years. For instance, A. Deich, a Soviet astronomer at the Pulkovo Observatory, by studying certain irregularities in the motion of Star 61 of the constellation of Cygnus, has definitely established that it has a dark satellite similar to the planets of the solar system. In the same way it has been discovered that other stars lying closest to the Sun, as Proxima Centauri, also have satellites. The development of science has thus confirmed the correctness of Giordano Bruno's prevision as to the existence of an endless number of systems similar to the solar system, a prevision for which he was burned at the stake 357 years ago.

Needless to say, the conditions necessary for the origin of life do not exist everywhere. And it must be admitted that these conditions are very demanding. They include a very limited temperature range, about 100° out of millions that are possible; the presence of an atmosphere, humidity, etc. Nevertheless, there are, without doubt, a countless number of planets with a rich biosphere, that is, planets inhabited by living beings. These living beings may be most diverse in form, they by no means have to resem-

ble terrestrial beings, but, in principle, life in the boundless Universe should not differ from ours.

According to Engels, "life is the mode of existence of protein bodies"; consequently, living beings on distant worlds consist of protoplasm resembling our terrestrial protoplasm and having, as its basis, protein formed of one and the same chemical elements: carbon, hydrogen, oxygen, nitrogen, and others. Life will exist on such heavenly bodies where protein compounds can be formed and can exist. This, in turn, means that reasonable, thinking beings can inhabit many distant worlds, for, as Engels said, "it is the nature of matter to advance to the evolution of thinking beings, hence this always necessarily occurs wherever the conditions for it (not necessarily identical at all places and times) are present."

As yet a visit to these distant worlds is still but a dream. Even if we ignore the technical difficulties, which are insuperable at the modern level of development of astronautics, difficulties involving an expenditure of colossal quantities of energy, the duration of such a journey at very great flight velocities will be many times greater than the duration of a human life.

However, with the further development of science certain possibilities may be revealed here. What we have in mind is not the prolongation of human life, for which Soviet science is striving, inasmuch as the "prolongation" necessary in the given case is beyond the possibilities of science. Certain unexpected prospects in this direction become possible as a result of increasing the ship's velocity to the velocity of light in a vacuum, which is the maximum speed possible in nature and is equal to 300,000 kilometres per second. Such velocities can be attained in principle if only the necessary energy were available.

It might seem that even such a tremendous velocity would be unable to solve the problem of interstellar flight, as the distances covered by such journeys are equivalent to many tens, thousands, and even millions of light-years. However, according to the latest theory of rapid motions, developed by modern physics (this theory is usually called the restricted or special theory of relativity), time, the fourth dimension, changes its flight speed when the velocity of motion closely approaches the velocity of light. On a ship moving at such a speed, the hours will drag very slowly. For instance, if a ship goes rushing away at a velocity

that is only one per cent less than the velocity of light, towards Star 61 of the constellation of Cygnus, where, as we have already mentioned above, Soviet astronomers discovered a planetary satellite, the time that will elapse from the moment the ship flies off to the moment it returns (the ship is considered as flying at one and the same speed all the time) will be, for inhabitants of the Earth, about 22 years, since this star is about 11 light years from the Earth. However, to the passengers on the ship it will seem that they have been on their "mission" only three years.

Such a slowing down of time when the speed of motion approximates the speed of light, is no longer mere hypothesis. There are experimental facts in modern science which can be explained only by means of this theory of rapid motions.

Should the velocity of the ship approximate the velocity of light even more, it will be able, in a brief period, to make excursions even to those corners of the Universe that are distant from the Sun. For instance, the ship will be able to fly in but a few "drawn-out" hours to the spiral nebula closest to our galaxy, in the constellation of Andromeda, which is at a distance of about a million light years from us.

True, even with such a velocity of interstellar ships the duration of the flight will be much more than that indicated, for much time will be required for the gradual, slow, take-off run of the ship (its acceleration will probably approximate the acceleration of the Earth's gravity) until it reaches this velocity, and then for a similarly slow braking. Yet in spite of all this, those velocities that approximate the velocity of light present extraordinary opportunities for interstellar flight.

The chief difficulty in making such flights is the colossal energy required for them. Calculations show that the energy of an engine of such a ship must be thousands of millions of kilowatts per ton of the ship's mass. Such power will become possible, of course, only when the problem of using the energy of the atomic nucleus has been completely solved. Even then, flights at velocities approximating the velocity of light will involve many fantastic difficulties. For instance, it is sufficient to mention the danger of collisions between the ship and particles of matter floating about in space.* During such a collision these particles

* It has been established that besides rarefied cosmic dust, atoms of hydrogen, helium, calcium, sodium, titanium and also other atoms and even molecules float about in interstellar space.

will be immeasurably more dangerous than the most powerful cosmic rays.

Special protective screens, tens of centimetres thick, will be needed to protect the passengers against the harmful radioactive radiation resulting from a collision with such particles. What should be said about a collision with a meteor, during which the ship will simply evaporate instantly!

But let us return from the distant future to the more real prospects of astronautics, those problems which this science must solve within the next few decades, that of making a flight to the planets of our solar system.

During flights to the planets, as distinct from a flight to the Moon, the space ship must travel considerable distances in the solar field of gravitation, since it moves either far away from the Sun or towards it. In this case we cannot ignore the attraction towards the Sun, as we did when discussing flights to the Moon or near the Earth. A considerable amount of energy will have to be consumed in overcoming the gravity of the Sun, and this may greatly complicate a flight to the planets, as compared to a flight to the Moon. The chief difficulty of such a flight, however, is its great duration if we are thinking of a manned flight. Only gradually, carefully, as we study all the specific features of a space flight, and what is most important, perhaps, its effect on man, will such flights to more distant goals become possible, and space ships will begin to make their way farther and farther into the space around the Sun.

There is practically no superimposition of the fields of attraction of the Earth and the planet to which the flight will be made, and it may, therefore, be ignored. These fields do not extend over very great distances. For practical purposes it may be considered that the attraction towards the Earth vanishes at distances over 800,000-1,000,000 kilometres, as it is so slight there. An iron ball weighing one kilogramme on Earth would weigh about 0.05 grammes at such a distance from the Earth, that is, about $^{1}/_{20000}$ as much.

A flight to any planet whatever will, therefore, consist of three different sections: a) the relatively small section of the flight in the terrestrial field of gravitation; b) that section of the flight which is in the planet's field of gravitation and which is also usually small; c) that section of the flight lying between the other two, which is longest in duration, and where only the solar attraction is felt.

An exact determination of the amount of fuel necessary to make a space flight, that is, the determination of the corresponding value of the ideal velocity, is most difficult at present. The general solution has not as yet been found, and the answer can be given only after numerous intricate calculations have been made on mathematical machines. This explains why we have to confine ourselves to approximate calculations of the value of the ideal velocity. However, these calculations are sufficiently exact to determine the question of whether one or another flight is or is not possible at the modern level of development of reaction technique.

If we consider a round-trip flight of a passenger space ship from the Earth to some other planet, with a landing on it and then back again to the Earth, it will be necessary, when determining the ideal velocity, to take into consideration the consumption of energy for the following chief purposes:

1) to overcome the terrestrial field of gravitation. The corresponding ideal velocity will be equal to the velocity of escape from the Earth;

2) to impart some velocity to the ship beyond the Earth's field of gravitation. This is necessary in order to make the flight to its goal possible, and to reduce the duration of the flight. At a low flight speed in the solar field of gravitation along the main section of the route, the flight will last extraordinarily long because of the tremendous distances that have to be traversed during this flight;

3) to overcome the planet's field of gravitation twice, once when the ship brakes on landing if the planet has no atmosphere which can be used for this purpose, and also on its return take-off;

4) to equalize the velocities of the ship and the planet and, on its return, with that of the Earth, for usually these velocities will be different when they meet.

Furthermore, energy will have to be spent in overcoming atmospheric resistance and losses in the ship's velocity when it is gaining altitude or when making a powered landing, also when manoeuvring, or because of navigational errors, etc.

All this necessary power must be stored up in the ship at the take-off if it is not planned to use any other sources of energy during the flight, as, for instance, solar energy, or if it is not intended to refuel during flight at some intermediate base, artificial or natural.

The supply of energy on the ship at take-off consists not only of the ener-

gy of the fuel stored up in the ship's tanks. The ship possesses a very considerable amount of kinetic energy, since, together with the Earth, it revolves around the Sun in its orbit at a velocity of about 29.8 kilometres per second. Furthermore, it possesses a relatively small amount of kinetic energy as a result of revolving around the terrestrial axis. If the ship's flight is properly directed, this kinetic energy can and should be used.

Approximate calculations show that the minimum ideal velocity for a one-way flight to Mars with a landing on it should be equal to about 25 kilometres per second, that is, the same as for a round trip from the Earth to the Moon and back. A similar trip to Venus would require a greater velocity, about 30 kilometres per second, because of this planet's greater mass. A decrease in the duration of the flight would require an additional increase in the ideal velocity. Obviously, at the present level of development of jet technique even these simplest of space flights are impossible.

A much simpler undertaking will be to make a flight to these planets without landing on them, merely for the purpose of flying around the planet at a small distance from it to photograph its surface and to make various observations. Such a flight around Venus would require only about half the ideal velocity, that is, it could be made with about the same amount of fuel as is needed to fly to the Moon and land on it.

About the same amount of fuel would be necessary to fly to these planets and land on their satellites. Unfortunately, Venus has no satellites, but it is almost beyond doubt that a landing will be made on Mars' satellites before landing on Mars itself.

However, even such simple flights to Mars and Venus are at present impossible, especially if we are thinking of manned flights. If they are to become possible, the jet velocity of the rocket motor must be increased to twice its present value, that is, to 5-6 kilometres per second. This problem cannot be solved with chemical fuels.

This task can be solved by using artificial refuelling stations, the Earth's satellites. With their help it would be possible, even today, to attempt a round trip to Mars with a landing on it. However, such artificial satellites cannot solve the problem of flights to the outer planets of the solar system, beginning with Jupiter, until new fuels are created. This is chiefly due to the tremendous duration of such flights. If the duration of these flights is to be decreased, the flight speed of the space ship must

be greatly increased, which, in turn, demands a manifold increase in the necessary fuel supply.

The duration of a flight to the planets will depend chiefly on the velocity selected and on the route. A flight to Mars and to Venus will probably last several months, while one to Jupiter and the remoter planets—years.

In the future, when regular passenger space trips between various points in the "inhabited" solar system will have been organized, the most popular flights will be those with transfers, for they will be most advantageous as regards fuel consumption. For instance, it will require much less fuel if a terrestrial passenger making a trip to Mars travels not by through express, but transfers at a space station for a ship travelling from Venus to Mars.

As yet we can only dream of the day when astronauts landing on the satellites of Mars, Jupiter or Saturn, will see such fascinating pictures as those presented by these planets at such a temptingly close distance.

The first to be studied will, of course. be the mysterious, exciting world of Mars and its minute satellites, Phobos and Deimos.* Against the sky of Mars' closest satellite, Phobos, Mars will look like a tremendous disc 90 times larger than the lunar. Even when viewed from its other satellite, Deimos, which is 23,500 kilometres from it, Mars will be visible in all its details.

Phobos, which is 41 times closer to Mars than the Moon is to the Earth (9,380 kilometres), and whose diameter is equal to about 15 kilometres, will be very much like a special observation point above the surface of Mars, similar to the artificial satellites of the Earth mentioned above. It will take Phobos 7 hours 39 minutes to make one revolution around Mars, a month on Mars, if figured according to Phobos, is approximately $^5/_{16}$ of a Martian day.

It will be dangerous to approach the giant Jupiter because of the possibility of falling into the net of its gravitation for ever. Observations of Jupiter will be made from its satellites, which are at a respectful distance from their planet. Jupiter's second satellite, Europa, discovered

* Phobos and Deimos—from the Greek meaning "fear" and "dread." Both of these harmless satellites owe their ominous names to Greek mythology, according to which Mars, the god of war, had two horses with such names.

by Galileo, and which is 670,000 kilometres from Jupiter, will very likely be suitable for this purpose. Since Europa's surface reflects the solar rays much better than Jupiter itself does, the conclusion may be drawn that this satellite is covered with frozen gases and ice.

Views of Saturn from its satellites will be especially beautiful because of the precious necklace this planet wears. But even at such a close distance Saturn's rings will, as usual, be a barely visible line across the planet's disc, for they are so thin.* Incidentally, if viewed from Saturn itself, the rings would very likely be much more beautiful. In any case, Saturn's sky, ornamented by a wide rainbow of rings that were always suspended above the equator, and which embraced the firmament from horizon to horizon, would, in the transparent dark haze that touches the surface of the planet, present a very unusual view to the terrestrial dwellers.

Chapter 15

COSMIC ROUTES

People feel a just sense of pride when they think of the last ocean they have conquered, the ocean of air. For centuries this fifth ocean, whose shores are inhabited by every single person, no matter where he lives, remained an unattainable dream. Only the achievements of many branches of science and technique have made the conquest of this ocean possible.

And yet how insignificant this victory seems when compared with the task facing mankind today, a task set us by the whole trend of science and technique, the task of conquering the last of the unconquered oceans, the ocean of space! Everything connected with this undertaking is so unusual, so unprecedented; it all demands such a sharp change in the old conceptions; it is all based on a combination of wild fantasy and soberest calculation.

And just as all the conquered oceans are but insignificant pools when compared with those boundless expanses that we still have to subdue, just so great are the difficulties that have to be overcome.

* An exact model of Saturn's rings would be in the form of a disc cut out of tissue paper and having a diameter of 30 metres. The diameter of Saturn's rings is 2.3 times greater than the diameter of the planet itself, and is equal to 275,000 kilometres, whereas the rings are not more than 15 kilometres thick.

The problem of astronavigation, that is, the problem of guiding celestial ships over invisible routes in space, is grandiose in character, newness and intricacy. How shall we calculate the flight? How shall we select an itinerary which will not demand any extra consumption of fuel and at the same time will not be inordinately long? How can we find our distant goal in space? How can we determine our position in it when we are millions of kilometres from any possible bearing? These and many other problems of astronavigation must first be solved, or it will be impossible to organize even the simplest cosmic flight. And each of these questions is a task the like of which science has never before been called upon to solve.

The tasks set by astronavigation are so unusual because they concern navigation in three dimensions. Any trip on Earth, no matter how long it may last, is, after all, a trip along a surface and not in space. The feeble attempts to use the third dimension, made by captains of submarine boats and commanders of airships, do not alter the case. A bit below the surface of the water or a bit above the surface of the land is just the same as moving along the surface. However, in astronautics all three dimensions are of equal value and the path must be laid not along some surface, but in space.

True, even here it must be noted that one of the dimensions is not beyond reproach, at least when considering flights within the solar system. As we know, almost all the planets of the solar system (with the exception of Pluto, the outermost planet) and their satellites revolve around the Sun along orbits which practically lie in one plane, called the ecliptic.* This means that the flight of a space ship must, in the main, take place in this one plane. Thus, the plane of the ecliptic, to some extent, acts as substitute for the Earth's surface, when we attempt to solve the tasks of astronavigation.

To be sure, when calculating cosmic routes we must take into consideration to what extent the planes of the orbits of the planets are deflected from the ecliptic. For instance, Mars, the plane of whose orbit is at an angle of 1.9° with the ecliptic, will be deflected from it no more than eight million kilometres. It would certainly be a pity to miss one's destination by that much!

* Ecliptic—the plane in which the Earth revolves around the Sun.

But astronavigation is not merely navigation in boundless space; it is navigation in such space where there are active powerful fields of gravitation. The force exerted by these fields upon a space ship not only changes from one point in space to another, but even changes with time, at a given point in space. And the trajectory of the flight of a space ship changes under the influence of these forces, which, in turn, are governed by certain very complex laws. At any rate, science is as yet unable to calculate this trajectory in advance; it can be determined only approximately. It is simply up to us to see to it that these errors in calculation are not too great, but even this is obviously not such a simple task. When we bear in mind the tremendous distances traversed by the space ship, even the slightest mistake, as in calculating direction, may carry the ship many millions of kilometres away from its destination.

The task is further extremely complicated by the fact that the destinations in astronavigation behave much worse than terrestrial goals, which are firmly attached to the Earth's surface. The pilot of a sea-going vessel or an airship would hardly be delighted to know that the destination he was heading for kept changing its position on the surface of the Earth according to certain intricate laws. Yet the laws governing the motions of heavenly bodies are incredibly more complex, and the smaller a body is, the more complex are these laws, for the greater is the number of different perturbations its motion is subjected to. It is sufficient to point out that the exact formula which astronomers use to calculate, in advance, the motion of the Moon in the firmament, covers approximately 200 pages! Nor is this surprising, for such a formula must take into account 150 major and about 500 minor perturbations of various character. To calculate the trajectory of the Moon for several decades in advance, specialists, mathematicians, with a whole staff of calculators to help them, will have to work for years. It would even take a calculating machine, that "robot brain" which man has at his service to make various complex calculations, months to figure this out even though such a machine can calculate in one minute what it takes a mathematician a month to do.

Generally speaking, after shooting off from the Earth it is possible to hit any set point in space. But—try and hit it! The shooter is faced with truly fantastic difficulties when he attempts this. His target goes flying along the most complicated courses at a dizzy pace, changing its velocity all the time; the shooter himself also goes whirling

around in space; countless influences carry the bullet off from its path. Indeed, you won't hit your target merely by good aiming! It may often be necessary to shoot not only at some invisible target, but even in a direction opposite to that of the target at the moment of firing! Why, then, should we wonder if, when shooting in this way, even if we aim most painstakingly, we may miss our mark by several hundreds of thousands of kilometres.

And in spite of all this, the astronauts will be hardly worse off than, let us say, the first navigators, the unknown Columbuses, the first discoverers of many lands now on the map of the world. Sailing in unreliable boats, they set off over the boundless ocean on trips full of danger, riding through fog and storm and ice, not knowing when they would reach their goal or even if that goal existed at all. When our astronauts set off on their distant journey they will be armed with exact data about when and where they will arrive at their destination, and if this destination is the Moon, they will have maps of the lunar surface, which, for the number of details on it, will not be inferior to maps of many regions on Earth.

The determination of cosmic routes for space ships will be greatly simplified by the fact that the motors of the ships operate for an insignificantly small period as compared with the total duration of the flight. In fact, except for some very brief moments, throughout the flight the ship moves in airless space with its motor switched off, that is, it moves in a free flight.* In this case the law governing the motion of the ship is fully determined by those fields of gravitation in which the ship moves and by its velocity. Generally speaking, the value and direction of the ship's velocity at any particular point in space predetermine its entire further trip. Unfortunately this trajectory cannot always be calculated beforehand by mathematical methods. As a matter of fact, this can be done only in one case, the simplest—for a flight in the field of gravitation of one particular star.

In actual fact, the fields of gravitation of different heavenly bodies overlap, but in practice we often find that the influence of the field of one particular body, as that of the Earth, the Sun, or some other planet, dominates as compared with the others. We may, therefore, take into consideration only this one field and ignore the others. That is why, for instance, a flight from the Earth to Mars can be divided into three sections: the

* This should not be confused with Tsiolkovsky's flight in "free space," where the force of gravity does not exist.

initial section of the flight, which takes place in the field of only the Earth's gravitation, the main section, which is only in the field of solar gravitation, and the final part of the flight, in the field of Mars' gravitation.

The laws governing the motion of one body in the field of gravitation of another (the problem of two bodies) have been studied in detail and form the basis of celestial mechanics.* The planets move around the Sun and the satellites around their planets according to these laws. These laws will also govern the flight of space ships over each of the sections of the course mentioned above. In order to study the flight of the ship we have every right to use the conclusions of celestial mechanics, even though the founders of this science could hardly have foreseen this application of it.

Let us, for example, consider a free flight in the terrestrial field of gravitation. Such will be any flight up to a distance of 800,000 kilometres from the Earth** (if we don't take into consideration the length of time of the ship's take-off run with the motor operating, the so-called active section of the trajectory, and an altitude up to about 100 kilometres where the air resistance is felt). We must also exclude from the case we are discussing such areas near the Earth where we have to consider the lunar field of gravitation.

Under these conditions the ship's flight will proceed exactly like the flight of a missile fired from an artillery gun into airless space. The trajectory of such a flight will be fully determined by the direction and velocity of the missile at the time it flies out of the gun barrel.

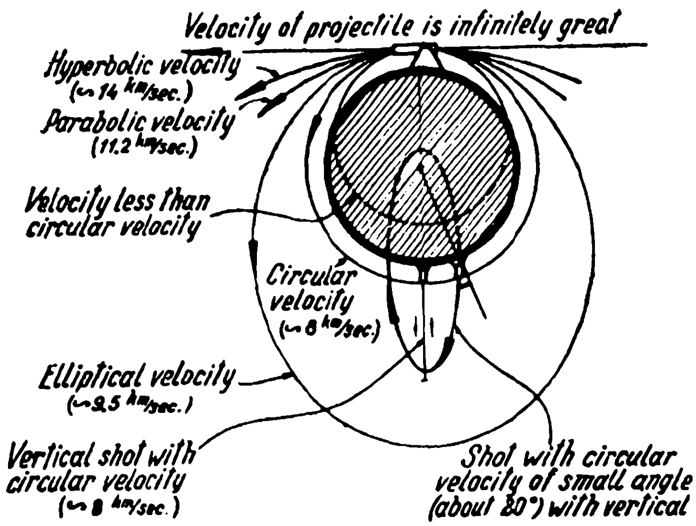
If the gun is set up vertically, the projectile will move from the centre of the Earth along the terrestrial radius. When the kinetic energy acquired by the projectile on being fired has been completely consumed in overcoming the Earth's gravitation, the projectile stops, then begins to fall back towards the Earth along the course it has already traversed,

* Celestial mechanics, that is, the theory of the motion of celestial bodies, is, of course, the problem of many bodies. However, since mathematics has as yet been unable to solve the simplest problem of this kind, the problem of three bodies, the problem of two bodies forms the basis of celestial mechanics, and the influence of the other bodies is taken into consideration as corresponding forces. Space flight is also a problem of celestial mechanics.

** At this distance the attraction towards the Earth becomes so little that it can be ignored.

and will re-enter the gun barrel with the same velocity with which it left it.*

The greater the initial velocity of the projectile, the higher it will rise above the Earth. We already know what this velocity should be if the projectile is not to return to the Earth, but is to come to a standstill only in "infinity." That is the escape velocity, which is equal to approximately 11.2 kilometres per second** on the surface of the Earth. If the velocity is less, the missile will fly for a strictly definite time until it reaches a certain maximum altitude, and then will fall back to the Earth. Thus, at a speed of 7.9 kilometres per second (at the equator) the missile will reach an altitude equal to the terrestrial radius, 6,378 kilometres.



Trajectory of projectile when fired from cannon set up horizontally.

Let us now set the cannon up horizontally, as if getting ready to fire straight at our target. If the initial velocity is small, our projectile will fly a short time and then fall back to the Earth, describing a small arc above it, part of an ellipse.***

According to celestial mechanics, the trajectory of the motion of one heavy body in the field of gravitation of another can be only one of the

* This is a simplification of the case. In reality the situation is much more complex.

** At the equator it is equal to 11.18 kilometres a second, at the poles—11.21 kilometres per second. Inasmuch as the Earth is not a perfect sphere in shape, the attraction towards the Earth at the poles will be greater, as the distance to the centre of the Earth is less. Furthermore, the force of gravity is less at the equator as a result of the centrifugal force caused by the rotation of the Earth on its axis. This force is completely absent at the pole.

*** It is usually considered that the projectile falls along a parabola, but such is not the case. It would move along a parabola if the Earth were flat. Bend this "flat" Earth into a sphere and the parabola becomes an ellipse. When the projectile flies a relatively small distance, this difference is practically imperceptible; when the firing distance is increased, it cannot be ignored.

curves which are called conic sections. The circle, ellipse, parabola and hyperbola are such curves. We can obtain these curves by cutting the cone with a plane as shown in the figure on page *164*. The projectile can move about the Earth's centre only along one of these curves (or along the Earth's radius, as when fired vertically).

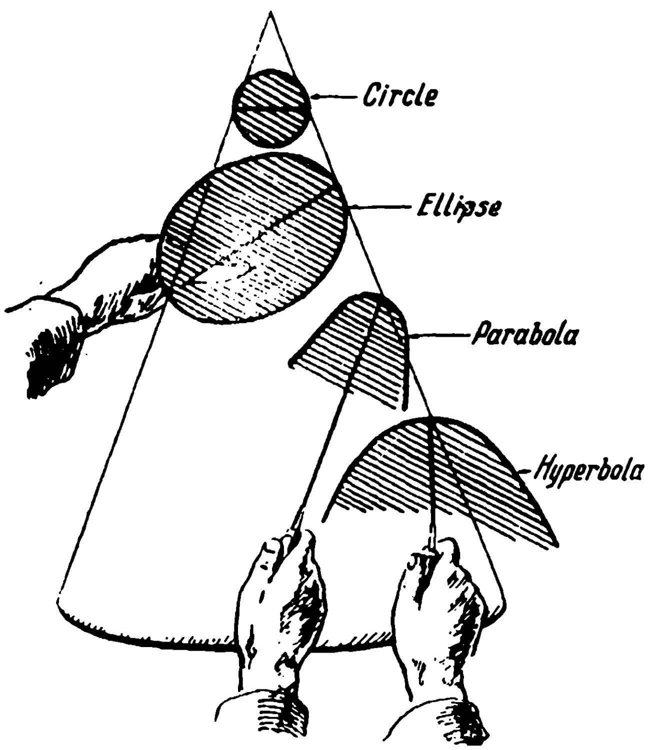
If the terrestrial surface did not stop the projectile, it would continue its motion along an ellipse until this ellipse closed, so that the projectile would fly into the gun barrel through its breech. The Earth's centre would be one of the two focuses of this ellipse.

The greater the initial velocity of the projectile, the more the ellipse approximates a circle in form until such a velocity is attained at which the projectile's orbit becomes a circle with the Earth's centre as its centre. The projectile will not fall now, but will circuit the Earth endlessly, flying every time through the barrel of the gun from which it was fired. We have already spoken in detail of such artificial terrestrial satellites. As we have pointed out, the initial velocity of a projectile necessary to transform it into a satellite, that is, the so-called circular velocity, is equal to 7.9 kilometres a second at the surface of the Earth; it is $^5/_7$ of the escape velocity. It will take such a satellite 1 hour 24 minutes to make one complete revolution around the Earth at its surface.

If the initial velocity of the projectile is further increased, it will be forced to move again along an elliptical orbit, but this time the Earth's centre will coincide with the second focus of the ellipse, that closer to the gun. The projectile will continue to rise higher and higher above the Earth's surface at the point which is the gun's antipode, that is, a point on the other side of the globe. It is interesting to compare the maximum altitudes attained by the projectile when fired with one and the same velocity from a gun in a horizontal and in a vertical position. The shot that is fired straight upwards will, of course, prove the more advantageous one here. When the velocity of the projectile is equal to the circular, that is, to 7.9 kilometres a second, it will, when fired vertically, rise to an altitude equal to one terrestrial radius, whereas when fired from a gun in a horizontal position it will remain near the Earth's surface. This difference of one terrestrial radius, 6,378 kilometres, is maintained even when the projectile's velocity is further increased. However, a projectile that has been vertically fired will, on reaching its maximum altitude, completely lose its velocity,

whereas its rival keeps whirling around the Earth at a tremendous speed. A "shot upwards," as we shall see later on, may be compared to the flight of a space ship at take-off; a "horizontal shot"—to the flight of the ship when it lands.

A shot from a gun placed at an angle with the Earth will come somewhere between the two extremes discussed above. The closer the gun's position is to the vertical, the more elongated will be the elliptical trajectory of the flight, the higher it will fly, and the less will be its speed at its maximum distance from the Earth.



Conical sections.

The following characteristic of elliptical orbits is of great importance for astronautics. When the initial velocity of the projectile is so great that it flies far away from the Earth, an insignificant increase in its speed greatly changes the orbit of the projectile's flight: the ellipse becomes more elongated, so that the maximum altitude of its flight will be greatly increased. For instance, if we increase the initial velocity of a projectile fired horizontally by merely 11 metres per second, that is, from 11,115 to 11,126 metres per second, the maximum altitude attained by the projectile above the Earth's surface will be increased from 475,000 to 630,000 kilometres. This goes to show how very exact the instruments regulating the flight of the space ship must be, in particular those which determine the moment when the motor is switched off, and also how difficult the problem of steering the space ship is.

An initial velocity of the projectile equal to the escape velocity will send it off into infinity, whether it is fired vertically or horizontally. As soon as the initial velocity of the projectile acquires this value, the elliptical orbit breaks, and the projectile no longer flies along a closed, but along

an open curve, a parabola. That is why the escape velocity is also called the parabolic velocity.

A further increase in the initial velocity of the projectile when fired, one that is greater than the parabolic, will send it flying along a hyperbolic curve and not along a parabola, and this curve will "open" more and more as the velocity increases. Such velocities are called hyperbolic.*

A projectile fired at a parabolic velocity of 11.2 kilometres per second possesses sufficient energy to escape from the fetters of the Earth's gravitation. This will not, however, save it from the influence of solar gravitation, and it will inevitably fall into the incandescent embrace of the Sun or will begin to revolve around it along an elliptical orbit. If it is to get away from the solar system, the velocity of the projectile must be parabolic in relation to the Sun. This velocity is much greater than the velocity of escape from the Earth, for the solar field of gravitation is more powerful—it is equal to about 42.1 kilometres per second. On the planets that are farther from the Sun this velocity is less, of course, so that on Pluto it is only 6.7 kilometres per second. On the surface of the Sun it is equal to 618 kilometres per second, inasmuch as the force of gravity on the Sun is 28 times that on Earth. On the Sun a person would weigh 1.5-2 tons, and perhaps even more.

We could hardly hope to free ourselves from the fetters of solar gravitation were it not for the fact that the Earth is a satellite of the Sun and consequently revolves around it at a circular velocity. But this also means that if advantage is to be taken of the circular velocity of the Earth, the interstellar ship need not be imparted the entire parabolic velocity in relation to the Sun, but only the difference between that and the circular velocity, that is, $42.1-29.8=12.3$ kilometres per second.

It is now easy to calculate what the initial velocity of an interstellar ship should be at its take-off from the Earth. Apparently it must be equal to 16.7 kilometres per second (by making use of the Earth's rotation on

* A parabolic trajectory can never be attained in practice and is chiefly of theoretical interest, as transitional from closed trajectories, elliptical, to open ones, hyperbolic. If the trajectory were to be parabolic, it would be necessary to maintain an absolutely exact value for the parabolic speed. A slightly lesser speed would make the trajectory elliptical, slightly greater—hyperbolic. At relatively small distances these trajectories are practically indistinguishable, and merge into one.

its axis this velocity may be lessened to 16.2 kilometres per second). This velocity is often called the velocity of liberation.*

As we see, if we take advantage of the orbital velocity of the Earth, the liberation velocity is not so great, in fact it is less than the necessary ideal velocity for a flight to the Moon.

If the orbital velocity of the Earth is to be used to the fullest advantage, the take-off of an interstellar ship should be effected in the same direction as the Earth's motion in its orbit, that is, counter-clockwise when looking from a point located above the North Pole. If the take-off is effected in the opposite direction, the liberation velocity of the ship will no longer be equal to 16.7, but to 71.9 kilometres per second, as it will be necessary to impart to the ship a velocity equal not to the difference between the parabolic and circular velocities, but to their sum, that is, $42.1+29.8=71.9$ kilometres per second.**

What route should the captain of a space ship select when directing it, let us say, to Mars? Obviously, he will have no easy problem to solve when selecting his route, a job that will carry with it many responsibilities. It will not be easy for the reason that there are no roads awaiting him in space, no railways, no asphalted highways. The ship will fly wherever the hand of man directs it. Nor is it necessary to explain why the job is such a responsible one: an unfortunate selection of the route may greatly increase the duration of the flight and the necessary fuel supply to be taken on board.

But wouldn't it be possible once and for all to determine the best Earth-Mars route, so that the only thing to be done would be to set up some road signs as on our terrestrial highways?

Unfortunately no. The matter is not so simple as that. Aside from the fact that such a route would not be immobile in space, but would move about in it together with its initial and final stations, the Earth and Mars, the very nature of this route would depend on the specific features of the

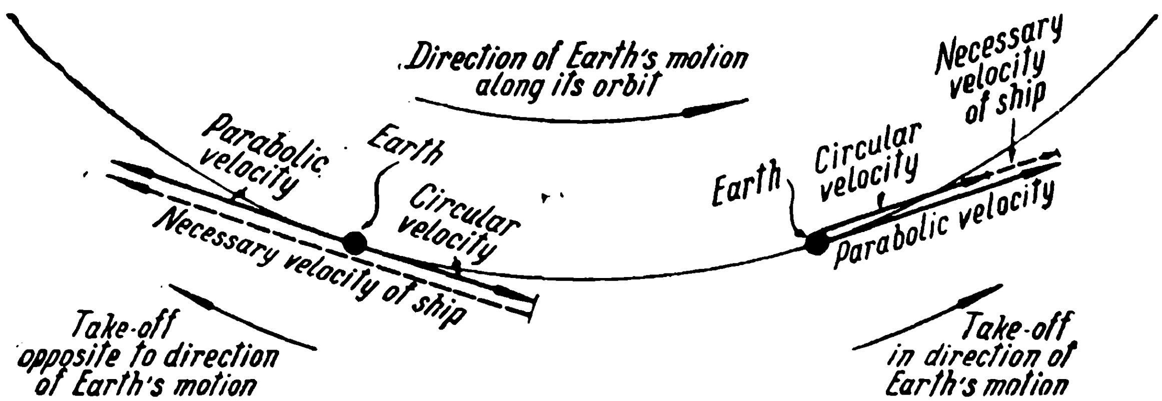
* We obtain the value for the velocity of liberation as follows: the kinetic energy of the ship at take-off from the Earth is proportional to the sum of the square of the escape velocity, that is, $11.2^2=126$ and the square of the necessary additional velocity, that is, $12.3^2=154$. It follows that the velocity of liberation is equal to $\sqrt{126+154}=\sqrt{280}\approx16.7$ kilometres per second.

** For practical purposes the flight of a space ship around the Sun must, in all cases, take place in the same direction as that in which the planets move. It is possible, of course, to fly in the opposite direction, but this involves a great expenditure of fuel.

flight. To find the most favourable route for a flight, given its duration or the fuel supply to be carried on the ship, is the most important problem in astronavigation. And the first thing one wants to know is what route will require the least consumption of fuel.

How would this problem be solved if a flight to Mars were undertaken?

Mars' orbit is greater than the Earth's, for Mars is farther from the Sun. It takes the Earth 365 days, or one year, to make one complete revolution



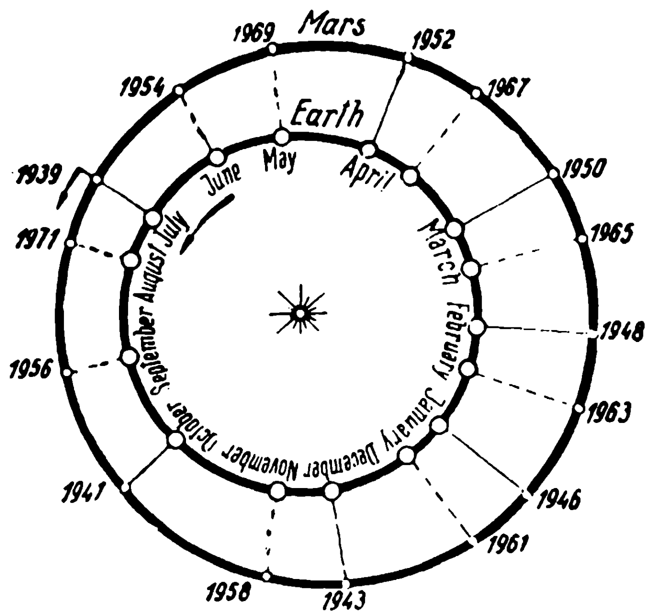
Magnitude of escape speed depends on the direction of the ship's take-off from the Earth.

in its orbit. It takes Mars 687 terrestrial days to make one complete revolution around the Sun. In other words, the Earth revolves around the Sun at an angular velocity that is twice as great; it makes slightly less than two revolutions in the time it takes Mars to circuit the Sun only once. As a result of this, Mars' oppositions, that is, those moments when Mars is closest to the Earth, come about once in two terrestrial years, or, to be more exact, once in 780 days.* Because of the considerable eccentricity of Mars' orbit, the distance to it during its opposition changes within great limits, from 56 to 100 million kilometres. Our ship might have made its trip in 1956, when the distance to Mars was the least. We shall have to wait 15 whole years ** for another such opportunity, when we shall witness the so-called great opposition. When this happens the distance separating Mars and the Earth along a straight line connecting their centres will be "only" 56 million kilometres. A mere "hand's stretch"!

* The so-called sidereal (or stellar) period of Mars' revolution is equal to 687 days; the synodical (or solar) period of revolution is 780 days.

** The great oppositions alternate every 15 or 17 years.

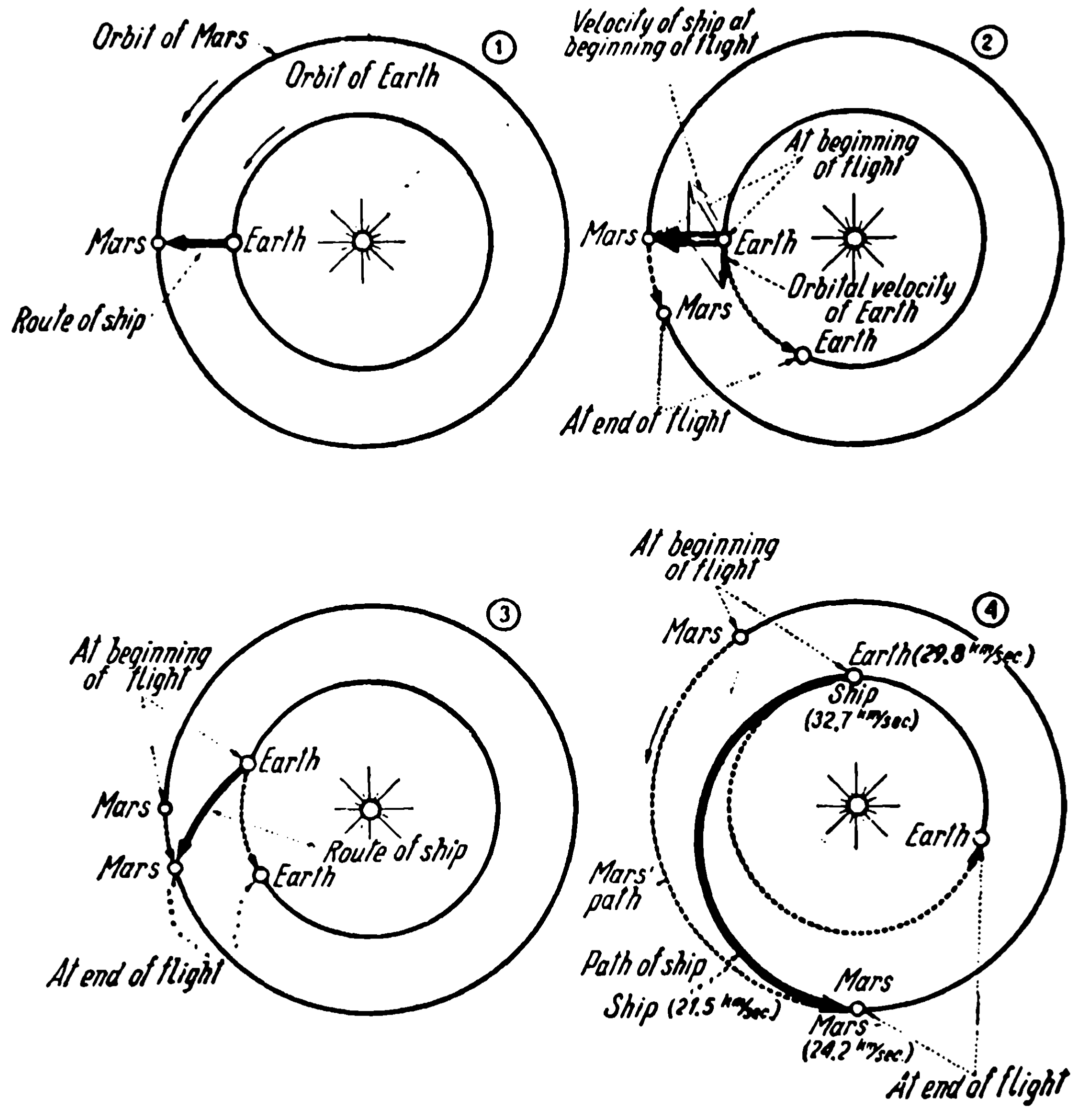
The simplest thing to do, it would seem, would be to direct the ship along this path, which is the shortest, but such is not the case. Furthermore, the ship would not be able to make its flight to Mars along such a path, for neither the Earth nor Mars is immobile, but they keep whirling around the Sun in their orbits. It would, of course, be possible to make the ship fly along this imaginary straight line if that were absolutely necessary, come what may, but it would be a meaningless undertaking. In the first place, when the ship reached Mars' orbit, after flying along such a straight line, it would not find the planet at the expected place, for Mars would have travelled on far ahead. Secondly, such a flight would involve a tremendous excess expenditure of fuel. If the ship were to move along such a straight line, it would have to be directed at an angle to it, otherwise it would be "carried off" in the direction of the Earth's motion in its orbit (just recall the way a person jumps off a moving tram). That is what the boatman does when he tries to cross the river along the shortest path—he directs his boat not straight across the river, but at an angle to it. This, however, makes it necessary to impart to the ship a much greater velocity if it is to reach Mars' orbit. Calculations show that the expenditure of energy on such a flight will be 2.5 times greater. That is what "rowing against the current" means!



Oppositions of Mars from 1939 to 1971.

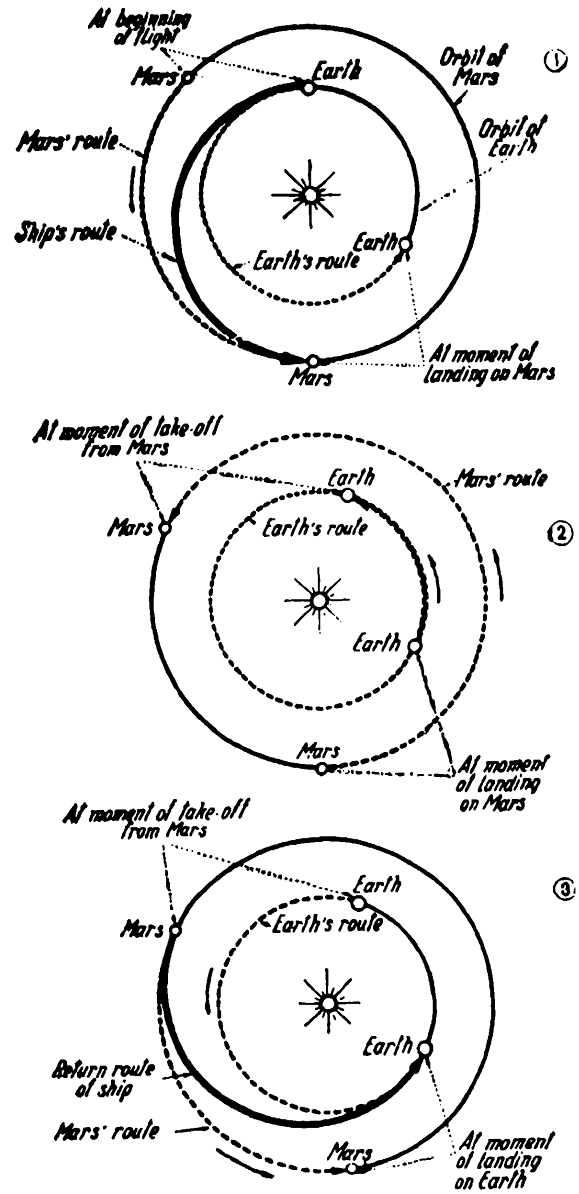
It is quite obvious that the shortest path between the orbits is by no means the most advantageous one. Of course an express ship, which pays little attention to the "expenses" of such a journey and is interested merely in making it in the shortest possible time, may, in spite of all, travel via the shortest route. Such an express flight could be made very quickly if only the necessary velocity were attainable.

However, the most advantageous flight from the point of view of fuel



How to fly to Mars: 1—flight via shortest route; Mars and the Earth are considered immobile at point of opposition; 2—flight via shortest route to orbit of Mars; necessary velocity of vessel is very great—it is necessary to "sail against current"; 3—flight of express ship may take two months and even less; 4—most effective flight, requiring least expenditure of fuel.

consumption will be one which takes place along a trajectory that makes full use of the circular velocity of the Earth in its revolution around the Sun. But this means that the ship's flight must proceed along a tangent to the Earth's orbit and in the same direction in which the Earth itself moves around the Sun. The take-off for such a flight should be about midnight, at which moment the point of take-off, if it is not at the pole, will



Flight of vessel to Mars and back along most advantageous route will last 2 years and 8 months: 1—258 days ship flies from the Earth to Mars; 2—454 days ship waits on Mars to start on its return trip almost two years after take-off from the Earth; 3—258 days it returns to the Earth.

be so situated that the ship can make use of the velocity this point has in its rotation on the terrestrial axis.

How should the initial velocity of the ship be selected? It is not so simple to answer this question, which is one of the most important in astronautics. Many factors have to be taken into consideration here, such as the level of development of jet technique (the jet velocity and other properties of the fuels, design of the ship, etc.), the required supplies of food, air and water for the passengers, and many other things. Calculations show* that the most advantageous trajectory is an ellipse which is tangent to both orbits, that of the Earth and that of Mars. In this case the initial and final points of the path lie on different sides of the Sun, on the major axis of the ellipse, which is equal to the diameter of the Earth's orbit plus the distance between the two orbits along the shortest path (that is, during the time of opposition). This means that the length varies from 355 to 400 million kilometres. The length of the corresponding semi-ellipse, which is the trajectory of the ship's flight, will be equal to approximately 600 million kilometres. A flight along such a path will take the ship about 240-270 days. For the ship to make such a flight its initial velocity beyond

* As yet the general solution for this problem has not been found.

the Earth's field of gravitation should be only 2.9 kilometres per second.

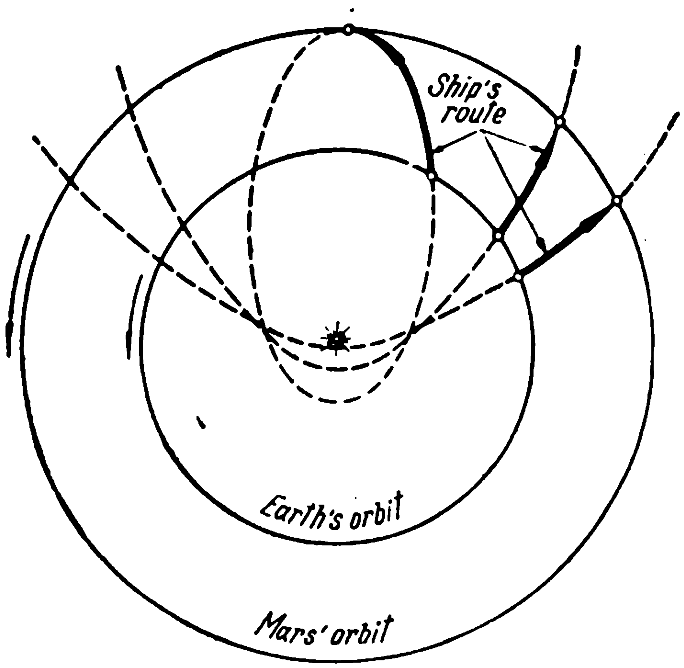
What, in this case, should be the ship's velocity when taking off from the Earth? Inasmuch as the ship should have an escape velocity of 11.2 kilometres per second to overcome the Earth's gravitation and, later, beyond the terrestrial field of gravitation, the ship's velocity should be 2.9 kilometres per second, one might be inclined to think that it will be necessary to impart to the ship at take-off a velocity of $11.2+2.9=14.1$ kilometres per second. This solution, however, would be an erroneous one. If we imparted this velocity to the ship, then beyond the field of terrestrial gravitation the ship's velocity would be 8.6 kilometres a second, and not 2.9. What strange arithmetic this is! An initial velocity of 14.1 kilometres per second; over 11 kilometres lost in overcoming the Earth's gravitation; and yet we have a remainder of 8.6 kilometres per second! As a matter of fact, the ship's velocity at take-off should be only 11.6 kilometres per second.*

We thus see how much more advantageous it is to impart to the ship all the velocity possible at take-off, which is practically a law in astronautics, an important law. If, in the given case, we imparted to the ship at take-off an escape velocity of only 11.2 kilometres per second and then, when it was beyond the field of terrestrial gravitation, we imparted another 2.9 kilometres per second to it, the total ideal velocity would be equal to 14.1, as we pointed out above, instead of 11.6 kilometres per second. And the fuel supply required for the ship would have to be correspondingly greater. For instance, with a jet velocity of 3 kilometres per second, the ratio of the ship's masses at take-off would be increased from 48 to 110.

When calculating the total fuel consumption for the flight we must

* Let us recall the following: in overcoming the Earth's gravitation the ship spends a certain amount of kinetic energy, and this energy is proportional to the square of the velocity. This means that in overcoming the Earth's gravitation we must spend kinetic energy, which is proportional to the square of the escape velocity, or $11.2^2=126$. Beyond the field of the Earth's gravitation the kinetic energy should be proportional, in the case under discussion, to $2.9^2=8.4$. It follows, then, that the kinetic energy of the ship at take-off should be proportional to the sum of $126+8.4=$ $=134.4$ and its take-off speed, obviously, must be equal to $\sqrt{134.4}$ or 11.6 kilometres per second. The trajectory of the ship's flight in the Earth's field of gravitation will, therefore, be a hyperbola.

take into consideration the ship's velocity in relation to Mars at the moment they meet. This velocity must be retarded chiefly by motor braking as Mars' atmosphere is very rare. This means an additional expenditure of fuel. If the flight is made along a tangential semi-ellipse, at the moment the ship meets Mars its flight will be quicker than that of Mars by about 2.7 kilometres per second. It would be possible, of course, to select such a route that, when the ship was flying along it, this relative velocity would be equal to zero. Once again we see how difficult it is to select the most advantageous route.



Trajectories of express flights: Earth-Mars.

If the course over which the ship is to fly is to be the most advantageous one (the tangential ellipse), the moment of the ship's take-off must be determined exactly, for otherwise it may not find Mars at the "rendezvous." At the moment of take-off Mars must be at a very definite point in its orbit in relation to the Earth: it must be ahead of it by about $^1/_8$ of a complete revolution, that is, by 45°. Inasmuch as this relative position is repeated with the same regularity as the opposition, the next convenient moment for a flight to Mars will occur only 2 years 50 days later. Nature itself, we see, takes measures to dampen the ardour of astronauts—it will not be possible to make frequent flights to Mars (at least, not with the jet technique of the immediate future). It is probably for this reason that in the future these advantageous moments will be used to organize entire expeditions consisting of many space ships, when a whole interplanetary fleet will fly off practically at one time.

The situation as regards a return to the Earth will be even worse. It will be easy to postpone the departure from the Earth one day or more, without greatly inconveniencing the passengers. But how will space travellers feel if they have to wait about two years on inhospitable Mars

before they can turn their ship homewards? Simple calculation shows that after having made a successful landing on Mars, in the event that the ship flies along the most advantageous semi-ellipse, its passengers will really have to wait there about 15 months before the ship can start on its return trip, if it again wishes to take advantage of the best route.

A slight increase in the expenditure of fuel will make it possible to select other trajectories for the flight, not along a tangential ellipse, but along ellipses that intersect both orbits or at least one of them. This may lead to a substantial decrease in the duration of the flight, so that such routes may prove to be very interesting. For instance, by increasing the ship's velocity at the take-off from the Earth from 11.6 to 14.3 kilometres per second, we can reduce the duration of the flight by three months, as compared with the eight months the flight would take along the most advantageous route. By increasing the take-off velocity to 15.9 kilometres per second we can reduce the duration of the flight to only four months. This decrease in the duration of the flight is achieved not only because of the increase in the velocity, but also because the trajectory is shortened. We can lessen the duration of the flight even more by increasing the ship's velocity to the hyperbolic in relation to the Sun. If the ship's velocity were hundreds of kilometres per second, the flight to Mars would take only a week.

By changing from a tangential ellipse to secant ellipses and especially to hyperbolas, it becomes much easier to select the moment for the ship's take-off from the Earth. Under these conditions there are several months in the year when the ship can start on its journey. However, this makes practically no difference as regards the moment to be selected for the return trip from Mars. In order to avoid a too lengthy sojourn on that planet, it is possible to use an express ship on the way back to the Earth, one capable of flying along a hyperbolic orbit and at such a great speed that the ship will be able to "overtake" the Earth. However, this involves a considerable increase in the amount of fuel to be expended.

Flights to the outer planets of the solar system, those that are beyond Mars, can, in principle, be effected in the same way as a flight to Mars. As before, the ship will take off from the Earth about midnight, so that its velocity may be added to the velocities of the Earth's revolution in its orbit and its rotation on its axis. This enables the ship to fly farther

away from the Sun until it reaches the orbit of the planet towards which it is flying, at such a moment when the planet itself is there.

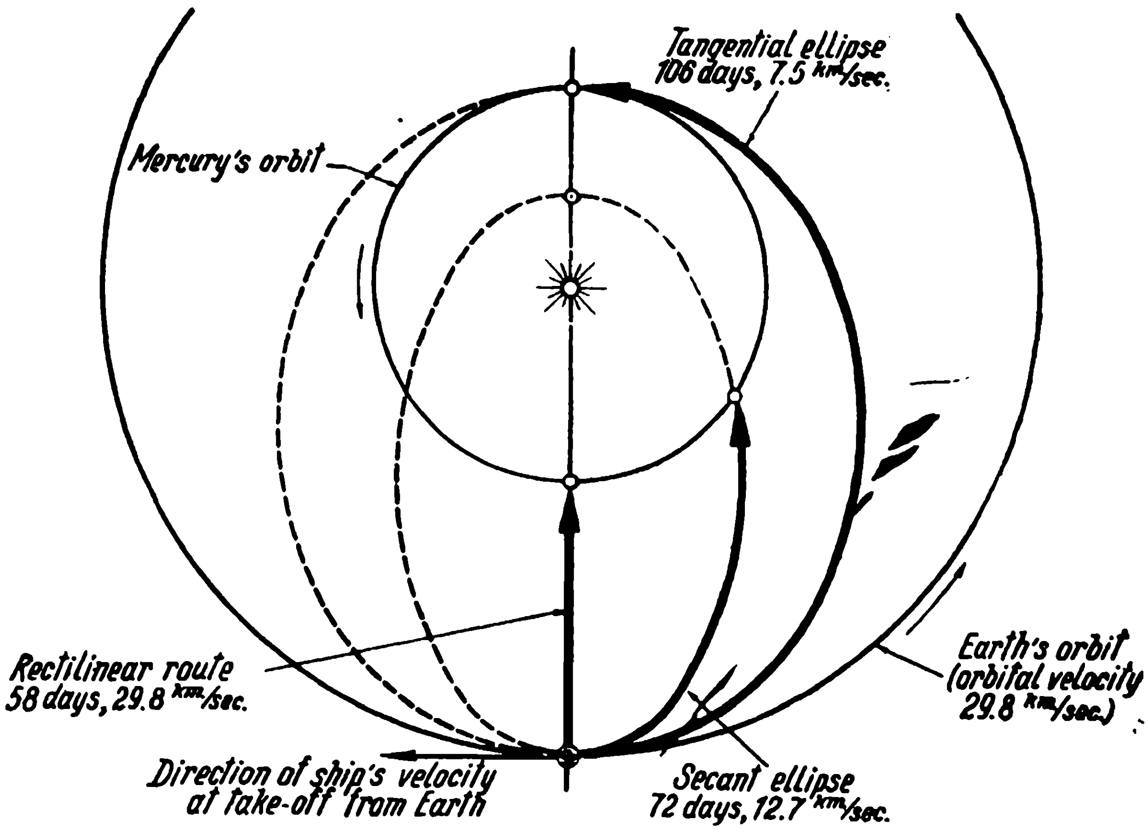
Flights to the inner planets, those whose orbits are less than the Earth's, in particular a flight to that "mysterious stranger," Venus, about which astronomers know so very little in spite of its proximity to our Earth, will have to be undertaken in quite a different way. In this case it will be sufficient to decrease the ship's velocity in comparison with the Earth's orbital speed, for the ship to begin to fall to the Sun, approaching it, until it reaches Venus' orbit. For this purpose the ship must take off from the Earth in a direction opposite to its motion around the Sun, that is, it must start about midday.* Beyond the terrestrial field of gravitation the ship's velocity should be equal to 2.4 kilometres per second and, consequently, the velocity of the take-off from the Earth should be less than 11.5 kilometres per second.** Under these conditions the ship will fly to Venus along the most advantageous route, a tangential semi-ellipse, making a trip of 400 million kilometres, although the shortest distance to Venus is only $^1/_{10}$ of this. In this case the flight to Venus will take slightly less than 5 months. As when taking off from Mars passengers will have to wait on Venus over 15 months before starting off on the return trip to the Earth along the most favourable route.

A flight to Venus along ellipses which intersect the orbits of the Earth and Venus or at least one of these orbits, instead of along a tangential ellipse, will, as in the case of a trip to Mars, considerably reduce the duration of the flight while requiring a certain increase in the fuel to be expended. For instance, if the velocity at the boundary of the terrestrial field of gravitation is increased from 2.4 to 8 kilometres per second, the duration of the flight can be cut almost in half.

Tangential semi-ellipses are the most advantageous trajectories from the viewpoint of fuel expenditure also when flights to other planets of the solar system are being considered. This, by the way, is indicative of another feature of astronautics: the most advantageous flight to a closer planet will sometimes last longer than a flight to a more distant planet.

* In order to use the velocity of the Earth's rotation on its axis. When flying off from the pole, the ship may take off at any time of day.

** $\sqrt{2.4^2+11.2^2}=11.5$.



Flight to Mercury along tangential and secant ellipses.

It is not very difficult to realize what we have in mind here: flights to the inner planets. Indeed, Venus is closer to the Earth than Mercury is, but since it is necessary to fly "to the other side" of the Sun, the path to Venus will be longer and will take more time.

There is another specific feature of astronautics connected with a flight to the inner planets which we must discuss: the less the velocity of the ship, the quicker it will reach its destination. This seems to prove the saying: "Slow and steady wins the race." The secret here is indeed simple. The less the velocity of the ship in relation to the Sun, the straighter and shorter will its path to it be, and the less the time spent by the ship in flying to its goal, whether Mercury or Venus. If, for instance, at the moment of take-off the ship were immobile in relation to the Sun, it would fall on it along a straight line, and in this case the flight to Venus or Mercury would be the shortest possible. But we must not forget that we are speaking of its velocity in relation to the Sun. For this velocity to be less, the ship's velocity in relation to the Earth at the moment of the take-off from the Earth must be greater, for in this case the ship flies off in

a direction opposite to the motion of the Earth in its orbit, and the ship's velocity must, therefore, make up for the orbital velocity of the Earth.

If the travellers have the time and patience, they can make some very interesting "promenades" in space without landing on any planet, but observing it at a close distance, one which must, however, be sufficiently respectful if they are not to be subjected to the considerable gravitation of the planet. These trips can be made with a minimum expenditure of fuel, just enough to send the ship off on an endless journey around the Sun after it has become transformed into a new planet, an asteroid. The corresponding velocity of the ship when taking off from Earth should be greater than the escape velocity (11.2 kilometres per second), but less than the liberation velocity (16.7 kilometres per second). After having selected a suitable moment for the take-off and the velocity, that is, the major axis of the ellipse, one can circuit the Sun several times, meet and observe the necessary planet, and then land on Earth, which, after having made several revolutions around the Sun in this period, will meet the ship at the place of its take-off. Such trips, including a study of Mars, Venus or Mercury, could be made in three years time. One to Jupiter would require 6 years, etc. Such a flight around Mars will require a take-off velocity of the ship of only 0.4-0.5 kilometres per second more than the escape velocity.

There is no doubt whatever that in the future cosmic routes will lie somewhere between the satellites, whether natural or artificial, and not directly between one planet and another.

It seems unnecessary to speak of the importance of correctly determining the position of the ship and the velocity and direction of its motion in space. The slightest mistake at the beginning of an elliptical trajectory may carry the ship off millions of kilometres from its destination. Such a mistake will often prove not only very difficult to correct, but even fatal in its consequences.

Many methods have been proposed to enable the pilot of the space ship to find his bearings in space. The time will come, of course, when this space will have routes equipped with refuelling stations, radio beacons, and the like, and then the crews on the "space fleet" will find life much easier. However, even then correct methods of astronavigation will be the most important means of ensuring the success of a flight.

As yet, radio-navigation in space is a thing of the more distant future, and astronauts have to use, as their bearings, the celestial luminaries, the Sun, the planets (including the one towards which the ship is flying), and the stars, which are always visible. Aviation today is already making use of the methods of astronavigation, that is, finding one's bearings by the stars. The first experiments in such orientation were made at the end of the past century from air balloons.

Astronavigation in space will be based on the achievements and experience of aviation astronavigation. However, flying in space will differ in many respects from flying within the limits of the Earth's atmosphere. Many more stars will be seen in the dark sky; the behaviour of the planets and the scorching Sun and many other phenomena will seem most unusual. One will be able to judge of the position of the ship in space by its distance from the Sun (this can be measured, for instance, by the temperature of a special thermocouple, heated by the solar rays), by the position of the Sun in the sky, by the position of the planets among the stars, as by the simultaneous photography of any two planets, etc. It will be necessary to develop special intricate methods of calculation and special instruments, and to make stellar maps.* The pilot of a space ship will be "armed to the teeth" in his hand-to-hand fight with the boundless expanses of the cosmos.

However, when methods of radio-navigation are applied to astronautics, his task will be incomparably lighter. Radio beams will indicate the paths in space, and radio robot-pilots of cosmic ships will unerringly direct them to their distant goals. Even so, a radio beam whirling through space at a speed of 300,000 kilometres per second will sometimes "give up." The pilot-radio officer of a space ship must never, not for a single instant, forget a certain something which radio officers on airplanes never have to think of, namely, the time it takes a radio beam to cover tremendous distances in space.

* It is interesting to note that maps for pilots of space ships may be made according to a system of "conditional meridians," developed by Soviet pilots making flights in the region of the North Pole. This system does away with the inconvenience caused by the intersection of all the terrestrial meridians at the point of the pole (at this point even a watch which has stopped shows the correct time). According to this system conditional meridians are drawn, which intersect only in infinity. The meridians of the solar system also intersect in infinity.

Chapter 16

THE TAKE-OFF AND THE LANDING

Those famous "three points" when making landing at an airfield probably cause aviation students more worry than anything else.

And very likely the most unpleasant moment in a space flight, will be the landing, although for other reasons than in aviation. The take-off of a space ship, too, is unpleasant in its own way. The students at a school for commanders of space ships will probably have to make many a take-off and landing with an instructor before they receive the precious right to make an independent flight.

The take-off of a space ship! What a thrilling sight that will be! How often has man thought of these stirring moments, when he parts from his native Earth to make a gigantic leap towards distant worlds! But it is much easier to picture the last tense moments before the ship takes off, the touching farewells and final requests, such as to convey one's greetings to Martian acquaintances, than to think of everything necessary for a successful start.

And the things that have to be thought of are indeed many. For instance, there is the time set for the take-off, the direction of the take-off, the velocity, the "programme" for the further flight in the Earth's atmosphere, the expenditure of fuel for the take-off, the well-being of the passengers, etc., etc.

The simplest question to decide is where the space ship will take off. Fortunately, the cosmoport can be located almost anywhere on Earth, so that future space travellers will not have to go to the equator to fly off, as some proposed doing. True, there is some advantage to be had if the take-off is at the equator, for in this case the velocity of the Earth's rotation on its axis can be used to the utmost. If the ship takes off at the equator, an additional velocity of 465 metres per second will be imparted to it as a result of this rotation. The greater the latitude where the ship takes off, that is, the nearer this place is to the poles, the less the gain, until it becomes equal to zero if the take-off is at the poles. If the cosmoport is situated in the middle latitudes, as, for instance, near Moscow, the increase in velocity will be approximately 260 metres per second. It would hardly be worth while, however, setting off for the tropics in pursuit of the other

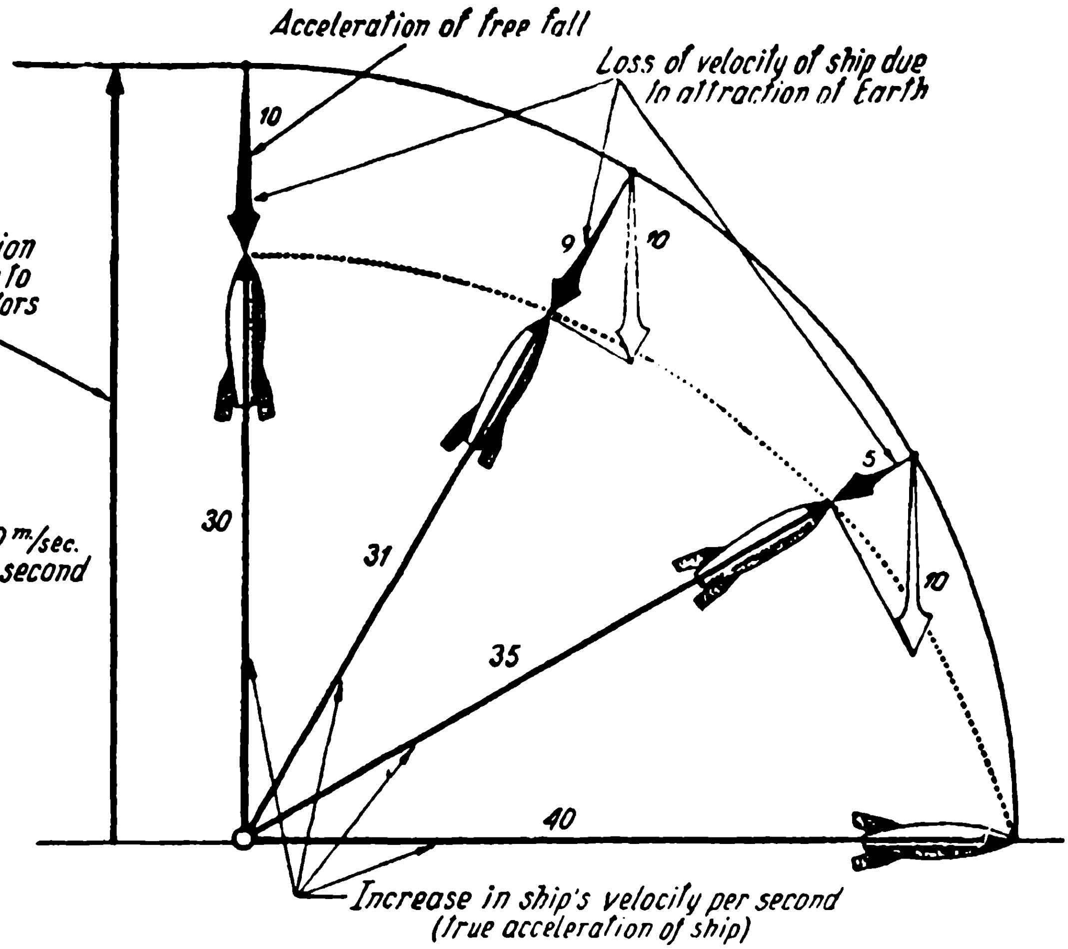
200 metres, even though a take-off from some high-mountain plateau in the Caucasus or the Pamirs would be more advantageous in many respects.

The time set for the departure of the ship does not necessarily have to be calculated too exactly, that is, to the second or fraction of a second, as some writers state, so that in this respect, too, the undertaking is relatively simple. At any rate, there will be no danger of having to postpone the flight to the next day or perhaps the following year just because a particular second set for the flight is already past. Yet we will not be completely free in choosing whatever time we wish. For instance, as we have already pointed out in the preceding chapter, flights in the direction of the Sun should start during the day; flights directed away from the Sun—at night. The best time will be determined by the geographical coordinates, the time of year, the destination, etc.

A much more serious question is the direction the ship's flight should take. This question was thoroughly studied by Tsiolkovsky. There are two contradictory demands that have to be taken into consideration here. On the one hand, it is desirable that the flight in the Earth's atmosphere be as short as possible, for this will decrease losses in velocity due to air resistance. And in order to attain this, it would be expedient to traverse the atmosphere via the shortest path, that is, make a vertical take-off. On the other hand, a vertical take-off involves new losses in the velocity of the ship due to the force of gravity (the so-called gravitational losses). If the ship flies off vertically, the influence of the force of attraction towards the Earth will decrease the final velocity of the ship, which it acquired during its powered flight. The greater the time spent on such an ascent and the less the permissible accelerations during flight, the greater will this braking effect of the force of gravity be felt. If the acceleration imparted to the ship by the motor were equal only to the acceleration of the force of gravity, the ship would simply hang immobile in the air, without gaining altitude. This circumstance makes a horizontal take-off feasible, for then the force of gravity does not decrease the velocity of the ship. And this means that there will be no need to increase the necessary supply of fuel.

What, then, should be the direction selected: vertical, horizontal, oblique?

Generally speaking, it would be possible to select a most favourable angle for every individual take-off, depending on the accelerations allowable in flight, the frontal resistance of the ship, and other factors. This is



When the ship's take-off is more oblique, the loss in velocity due to force of gravity will be less.

how one usually pictures the take-off of a space ship: down a long take-off track leading off to a trestle bridge that extends high up into the sky. However, the take-off of a space ship will most probably be quite unlike this. It is more likely to resemble the launching of the heavy long-range rockets described in Chapter 6.

When ready for the take-off, the ship will probably be set up in a vertical position and will rest on its own supports, the chassis, which will be equipped with powerful shock absorbers like those of an airplane. The vertical position of the ship is practical from the viewpoint of its durability. The forces that act along the axis of the ship during the take-off and the landing are several times greater than the ship's own weight, so that the calculations of the ship take these longitudinal loads into account. Both the durability and rigidity of the ship, which has a very light skin, are

obviously insufficient in a lateral direction, for the vessel is not calculated for large transverse loads, and the horizontal position will, therefore, be undesirable. While on this subject it should be mentioned that the ship's landing on the planets, especially those devoid of atmosphere, will be effected from a vertical direction, also on such a supporting chassis.

The ship will fly off vertically and, rising into the sky also vertically, will begin to gain altitude in order to pass, as quickly as possible, through the densest strata of the atmosphere, those offering greatest resistance to the flight. At an altitude of between 10 and 20 kilometres, the steering gear of the ship, which until now sustained its vertical ascent, will deflect the flight from the vertical. The ship will begin to move along a curved trajectory, towards the east.

Just a word about steering the ship during flight. Everything written about astronautics, beginning with Tsiolkovsky's works, pays much attention to this question, which is quite natural, for a space ship must be readily controllable at any moment during its flight. Tsiolkovsky not only was the first to formulate the problem of steering a space ship, but he also suggested solutions for it, and nothing new, in principle, has been added to it since then. Some of these suggestions have already been widely applied in jet technique, in particular, for long-range guided rockets.* For purposes of steering during flight in the atmosphere, the ship should be equipped with air, aerodynamic rudders, similar to those employed in airplanes. However, these rudders can be of no use whatever during flight in airless space. Furthermore, even when the ship is flying in the atmosphere, they are not always capable of managing the task assigned them. Such is the case, for instance, at the beginning of the take-off, when the ship's velocity is insufficient for the rudders to be effective, and also during flight in the upper, rarefied atmosphere.

For this reason the ship will be supplied not only with air rudders, but also with gas rudders, that is, rudders located in the stream of gases escaping from the motor. A turn of the gas rudders will deflect the jet stream, creating lateral stress, which will change the direction of the ship's flight. In some cases, for this very same purpose, the engine is so installed in the rocket that it can turn about somewhat, changing the direction of the thrust.

* The very idea of automatic control of rocket flight was likewise Tsiolkovsky's. He also invented the robot-pilot which is so widely used in aviation today.

However, such methods are not suited for steering a ship flying in space, for it will not always be feasible and sometimes it will be simply impossible to start the main engine of the ship operating just for the purpose of steering. Control in space must, therefore, be based on other principles. For instance, one can install auxiliary rudder liquid-fuel rocket motors for this purpose.* One can also take advantage of the fact that a flying ship cannot be turned around its centre of gravity** without the aid of outside forces. That is why if a mass is rotated inside the ship in one direction, the ship itself will begin to rotate in the other direction. It follows, then, that for purposes of steering, we can install a rapidly rotating disc inside the ship. With its aid the ship can be turned in the desired direction.

In this way the ship can be turned only around its centre of gravity. However, we cannot get along without the engine if we wish to change the direction of the ship's flight.

But let us return to our flying ship. The powered flight of the ship along a curve will continue with an ever-increasing speed, gradually changing to an almost horizontal flight. At an altitude of about 100 kilometres the ship will be flying almost horizontally, at a very small angle with the horizon. The ship will continue to fly around the Earth in this fashion until its velocity becomes circular (about 7.9 kilometres per second). When its velocity exceeds the circular it will begin to move away from the Earth.

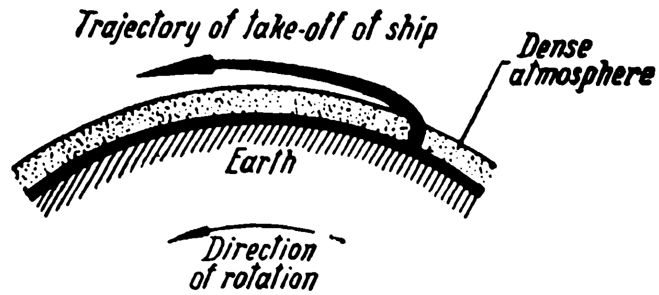
The duration of the take-off run of the ship, that is, the duration of its powered flight, will be determined by the value of its acceleration at take-off and the required velocity. Evidently, the greater the acceleration and the less the final velocity, the shorter will be the period of the take-off run. We have already spoken of the required final velocity; it should not be less than the escape velocity and perhaps much greater if an express flight is being made. The most probable final velocity will very likely come within the following range: from the escape velocity, which is about 11 kilometres per second, to the velocity of liberation, 16.7 kilometres per second.

As regards the ship's acceleration, the largest possible value should be selected. Theoretically, the most advantageous acceleration would be an

* It should be mentioned, in this connection, that the rotation of the ship, once it has been started by these motors, will continue until it is stopped by a push in the opposite direction.

** The so-called principle of conservation of angular momentum.

instantaneous increase in the ship's velocity from naught to the final velocity, for in this case there would be no losses in velocity connected with the take-off run of the ship. But this is impossible, of course. Furthermore, the accelerations during the take-off run of the ship should be quite small on the whole because of the inertia overloads which man can withstand. We shall speak of these in greater detail in Chapter 20. True, this is not the only factor that limits the allowable accelerations during take-off. Another factor is the durability of the ship: this is calculated for definite inertia overloads which, if increased, would call for a considerable increase in the ship's construction weight. And another consideration: the accelerations are limited by the fact that the ship's velocity at low altitudes in dense air cannot be too great because of the danger of overheating during flight, the chief danger during the landing of the ship. We shall discuss this later, when speaking of the ship's landing.



Trajectory of take-off of ship.

However, the decisive consideration is the effect of allowable inertia overloads when regarded from the viewpoint of the passengers' health. It is most likely that because of this the acceptable acceleration of the ship at take-off will be equal to approximately 40 metres per second for every second of the take-off run, that is, four times the acceleration of the Earth's gravity.

The accepted value for the acceleration means that during the vertical take-off of the ship, its velocity will increase 30 metres every second, and during a horizontal take-off—40 metres per second, as shown in the figure on page *180*. As the vertical ascent lasts until the ship reaches an altitude of 10-20 kilometres, it follows that by the end of the vertical take-off the ship's velocity will be about one kilometre per second. As we shall see later, at altitudes over 20 kilometres these velocities do not as yet present any danger from the point of view of overheating. A vertical ascent will take about 35-40 seconds, that is, in less than $^3/_4$ of a minute the ship will be at an altitude of about 20 kilometres. The further run of the ship

will proceed along a curved, ever more oblique trajectory, with the velocity increasing at an average of about 35 metres per second for every second.* Under this condition the final velocity of, let us say, 11.5 kilometres per second, will be reached when the ship has flown 1,600 kilometres. Such a flight will take about five minutes, while the total time spent on the powered run will be less than six minutes.

By the time the motor is switched off, that is, at the end of the so-called active section of the trajectory, the ship will very likely be at an altitude of slightly less than 1,000 kilometres above the Earth. This altitude must be taken into consideration when determining the necessary final velocity, for as the distance from the Earth increases, the escape velocity decreases. At an altitude of 1,000 kilometres the escape velocity will no longer be equal to 11.2 kilometres per second, but to about 10.5 kilometres per second, as a result of which the engine will not have to work so long and the expenditure of fuel will be correspondingly less.

However, this gain will most likely be offset by the losses in the ship's velocity at take-off as a result of the influence of the force of gravity. If we consider the average loss in velocity during the entire take-off run, due to the force of gravity, as two-three metres per second, the total loss will be 700-1,000 metres per second.

The resistance offered by the air to the space ship which is flying at a great speed will further decrease the velocity. Despite all the achievements of aerodynamics, the science of flight in the air, it is still impossible, at the present stage, to calculate precisely what the loss in the velocity of the space ship will be. The rapid development of jet technique has made it necessary to calculate the frontal resistance of airplanes flying at a speed approximating the speed of sound, and at altitudes of over 15 kilometres. The aerodynamics of great velocities, so-called gas dynamics, is mastering this task rather well. However, the flight of a space ship will take place under conditions that differ greatly from those under which the swiftest aircraft and modern high-altitude planes fly. The experience acquired in recent years when testing heavy long-range and stratospheric rockets is, to a large extent, applicable here, but this experience is as yet very little.

* For the sake of precaution, the loss in velocity accepted here is five metres per second, although the value given below, of two-three metres per second, is more likely.

A space ship, when taking off, undergoes a number of different experiences, beginning from the lowest velocities and altitudes and ending with a flight at tremendous altitudes in greatly rarefied atmosphere and at a colossal, cosmic velocity of tens of thousands of kilometres per hour, which is much greater than the speeds already achieved by technique.

As yet we do not know the exact laws of resistance during a flight under such conditions, although these problems are being studied most intensively, both theoretically and experimentally. At any rate it is clear that the phenomena which evoke resistance during such a flight are, as regards their physical aspects, different from the well-studied streamline phenomena, which accompany a flight in dense air at speeds approximating the velocity of sound. The main thing here is that when a flight takes place in dense air, the latter may be considered as a continuous, entirely liquid medium, so great is the number of air molecules colliding with the surface of the flying body every moment. However, the situation is quite different at a tremendous altitude, where the air is very rare. Under these conditions the flying body is not surrounded by a stream of compact "liquid," but is bombarded by a shower of isolated, free molecules. The resistance that arises when such free molecules flow around the ship is governed by quite different laws. Furthermore, there are various intermediate stages between these two extremes. An approximate calculation shows that the ship will encounter the greatest frontal resistance at an altitude of about 10 kilometres.

Because of this we can, today, estimate only approximately the loss in velocity of a space ship at take-off due to the resistance of the air. This loss will, of course, depend on the form and dimensions of the ship. Evidently the ship should have the form of a large winged rocket, at least at take-off. The wings, which are of great value at take-off as stabilizers and also because of the lifting power they develop, will likewise be necessary during landing, as we shall see later on. These wings will very likely be arrow-shaped and may be retractable, as they are in certain experimental airplanes. This will make it possible to change the area of the surface and the arrow-shaped form of the wings, depending on the ship's flight speed; as the take-off run increases, the wings will be withdrawn and their arrow-like shape increased.

Various spherical and other poor streamline forms sometimes proposed for the ships because of the absence of air resistance in space, cause

an unallowable loss of velocity at take-off. For this reason it is unlikely that they will find application. *

The greater the dimensions of the ship, the less will be the relative loss in velocity during the take-off as a result of air resistance.

Calculations made for a stratospheric rocket weighing 50 tons showed that the rocket velocity at the end of the active section of the trajectory, that is, by the time the rocket had finished its powered take-off run, had decreased by about five per cent due to air resistance. It can, therefore, be concluded that as regards heavy space ships, which fly chiefly in the upper, the most rarefied, atmosphere, the loss will be no more than this, and even less. We will not be making a great mistake if we assume that the loss in velocity of a space ship at take-off because of the resistance of the atmosphere will not exceed three per cent, that is, it will be about 300 metres per second.**

The total loss of velocity of a space ship at the take-off from the Earth will be equal to the sum of both losses caused by the Earth's gravitation and the resistance of the air. The value of this loss depends on a number of factors, but it will very likely be around 1,000-1,500 metres per second. This velocity should be added to the necessary final velocity of the ship at the end of the active section of the trajectory, in order to obtain the ideal velocity, which forms the basis for calculating the fuel supply for the ship. Consequently, in the best of cases, when only the escape velocity must be figured, and this, as we have seen above, can be taken as 10.5 kilometres per second, the ideal velocity will be equal to 11.5-12 kilometres per second.

To make a landing on the Moon or on any other heavenly body that has no atmosphere but which has its own field of gravitation, the velocity of the ship in relation to this body must be reduced by motor braking.

At a very definite distance from the surface of the celestial body, which has been figured out beforehand, it is necessary to switch in the motor of

* Observation in Moscow of one of the meteors showed that its velocity for a second of flight at an altitude of 40 kilometres decreased from 56 to 14 kilometres per second. That is how great aerodynamic braking is even when the flight takes place in very rare atmosphere. It sometimes reaches the figure of 100 kilometres per second for every second of flight.

** Even lower figures are given, as little as one per cent, but these, we feel, are too optimistic. During experimental launchings of the highest-altitude rockets this loss was as high as seven per cent.

the ship so that the jet force will gradually reduce the velocity of the ship to zero. If braking begins too early, at a great distance from the landing area, it will cause a considerable over-expenditure of fuel. In theory it would be best to cut down the ship's velocity all at once and have the ship stop suddenly, right at the very surface of the planet, but this is impossible, of course, and, therefore, when braking, the maximum allowable inertia overloads should be used.

If the planet has an atmosphere, even such a rare atmosphere as that of Mars, but especially if it is as dense as the atmosphere of the Earth or Venus, a considerable part of the total braking of the ship when landing may be accomplished by using the resistance offered the flying ship by this atmosphere. In this way a considerable amount of fuel may be saved, but...

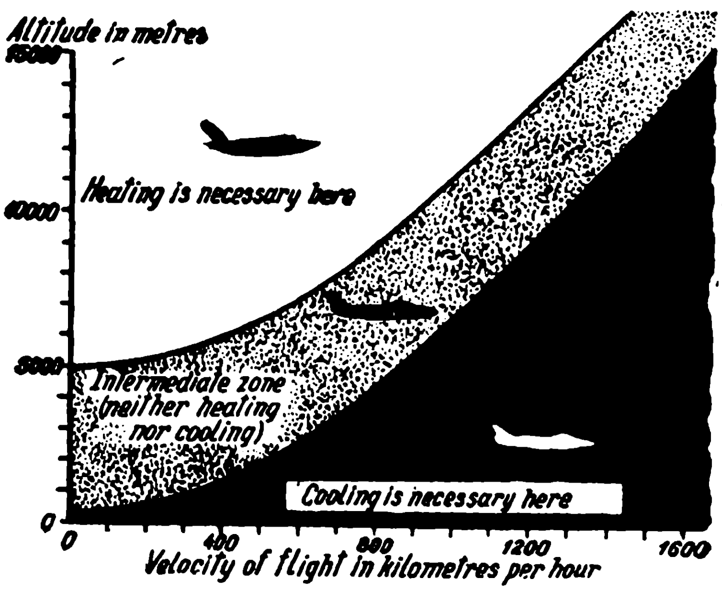
But such a landing is, literally speaking, "playing with fire," for the slightest mistake in calculations, a mistake on the part of the pilot, and the ship may flare up like a bright torch; in the best of cases, the only thing that will reach the surface of the planet will be the charred and molten remains of what was once a celestial ship. The fate of meteors which, as is said, "burn up" in the atmosphere, that is, which are destroyed in it by the blows of air molecules, will haunt the commander of a space ship who dared to risk such a landing* like an ominous phantom. And yet the possibility of making such a landing must not be ignored. The exact findings of science combined with faultless automatic control will make such a landing absolutely safe.

Even today high-speed aviation must take into consideration the phenomenon of overheating during flight. This overheating occurs because the airplane, whirling at a tremendous velocity, runs up against the immobile air and compresses it. The effect obtained would be the same as if a stream of air moving at a great speed ran up against an immobile surface and suddenly stopped, braking against this surface. When braking in this way the kinetic energy of the air stream is converted into heat which, conveyed to the surface of the plane, increases its temperature. At low flight speeds there is practically no overheating, as we know: the cabins of airplanes must

* It should be remembered that the velocity of a ship approaching the Earth will be about $^1/_5$ the velocity of evaporating meteors, and, therefore, the resistance offered the ship by the air, even if the form of the ship is the same, will be only $^1/_{25}$. Furthermore, the frontal resistance of the air encountered by meteors, whose form is irregular, will also be much greater for this reason.

be heated artificially because of the severe cold that prevails at high altitudes. But as the velocity increases, the aerodynamic heating up of the plane becomes so great* that finally it not only becomes unnecessary to heat the cabin, but measures must be taken to cool it.

Even today we have cases when the temperature in the cabins of speed jet planes rises to 60° C. and more. In the cabins of experimental planes, whose velocity is even greater, the temperature even rises to 100° C.



Graph showing dependence of temperature to which the ship is heated on flight velocity and altitude.

Obviously no amount of training will be of any good here. The problem of cooling the pilot's cabin becomes most urgent.

The heating up of the plane during flight in the air compels one to think not only of the pilot but of the plane itself. As we know, planes are built of light, durable alloys of aluminium and magnesium. But the durability of these alloys is quickly reduced as their temperature increases. The loaded parts made of these alloys can be used only up to relatively low temperatures, such as do not exceed approximately 200° C. A further increase in flight velocity with a corresponding increase in the heating up of the plane will, therefore, make it necessary to abandon the use of light alloys in airplane construction and to use other materials which have greater resistance to heat, but which, alas, are also heavier in weight.

This is why, in the latest speed planes, alloys of titanium, which are light in weight and preserve their durability even at higher temperatures, are coming into greater use. It is not without reason that titanium is sometimes called the metal of the future in aviation. For this reason, too, some

* Inasmuch as the kinetic energy is proportional to the square of the velocity of motion, the aerodynamic heating will also increase with the increase in the flight velocity, proportionately to its square.

of the latest aiplanes are built of stainless steel. This also explains why in the cabins of such planes, refrigerators,cooling units,are installed to cool the pilot and, at the same time, some of the most important parts of the plane. These units by no means resemble household refrigerators. They can produce a sufficient amount of cold to cool a theatre of average size on a hot day, creating a comfortable feeling of coolness inside.*

These measures are not, of course, radical ones, for they are not intended to overcome the aerodynamic heating up of the plane during flight, but are merely a means of adaptation to it. The future increase in flight velocity may make all these measures of no avail. Even today temperatures of many hundreds of degrees are reached during the flight of a stratospheric rocket. For instance, the long-range rocket described in Chapter 6, when falling to the Earth, becomes so heated up in the lower section of the trajectory of its flight that the temperature of its surface reaches 700° C.

The only possible means of overcoming the overheating of the plane during flight become quite obvious. These means, in many respects, determine the way in which aviation will develop further. They consist of increasing the ability of the airplanes to attain greater altitudes. Only at a great altitude can a 'plane fly quickly, and the quicker it flies, the higher will it fly. At great altitudes the air is rare. This decreases the resistance and, consequently, the necessary power of the motor which, when flying at a great speed near the Earth, might be disproportionately great. At the same time the plane heats up less at great altitudes. The rarefied air imparts less heat to it, while the radiation of this heat by the plane into the surrounding space is increased, so that the temperature of the plane's surface is lowered.

At very great cosmic speeds the flight should be made at very great altitudes, to avoid overheating. This danger will very likely be fully obviated at altitudes of 100 kilometres. It is at this altitude that meteors usually flare up. Cold celestial stones break into the atmosphere at a speed of tens of thousands of kilometres per hour. As a result of aerodynamic heating, the stones become extremely hot and in most cases "go up in smoke," become an incandescent, luminous clot of gas and steam, which we see as a "shooting star." To be more exact, what is luminous is chiefly a mass of dense, incandescent air whirling ahead in front of the meteor. Its tempera-

* This unit is of the turbine type. The air is cooled in it through expansion in a special turbine. A turbine in one of these units makes 100,000 revolutions per minute.

ture rises to 200,000° C. and its pressure—to hundreds of atmospheres. Only rare, the very largest meteors, or those having a smaller velocity, reach the Earth's surface. This explains why there are so few cases of falling meteors on Earth, whereas the total number which make their way daily into the Earth's atmosphere is so great.

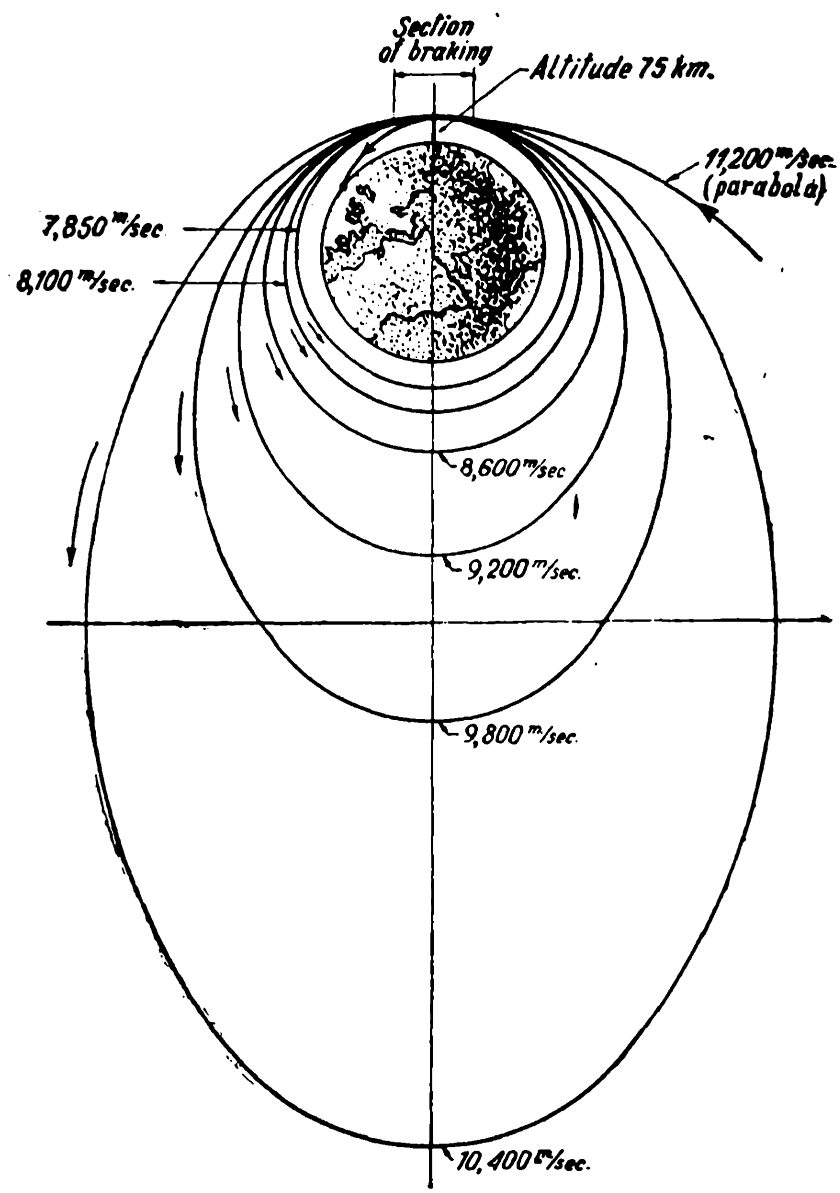
We can picture the landing of a ship on Earth as described below, although this problem will be finally solved only after much greater experience has been accumulated in flying planes and rockets in the upper atmosphere. The ship should approach the Earth at a small angle, so that the terrestrial field of gravitation will not affect its velocity much in the beginning. This is why the landing, as pointed out in the previous chapter, should resemble a shot fired from a gun horizontally. Then the motor is switched on and the ship's velocity is gradually lowered by jet braking. As the velocity of the ship decreases, its trajectory becomes steeper and the motor is switched off. This is at an altitude of from 50 to 100 kilometres. The further descent takes place by means of aerodynamic braking, in which the ship's wings play an important part. Additional braking can be obtained by means of aerodynamic brakes, flaps which are widely used in aviation. Special parachutes may be used for braking; these too have begun to find application in aviation.

When the ship's velocity is reduced to 100-150 metres per second, it begins to descend vertically by parachute, with its stern forward, its velocity of descent gradually dropping to 10-15 metres per second. Close to the Earth the ship's pilot switches in the motor again for a brief moment, the last push, retarding what is left of the velocity, and the ship smoothly, softly lands on its shock-absorbing supports. Back on Earth again!

Instead of reducing the ship's velocity by motor braking at the very beginning, on approaching the Earth, braking may be effected by using air resistance, as was proposed by Tsiolkovsky and later by Kondratyuk, Tsander and others. For this purpose the ship should make numerous flights around the Earth in elliptical orbits that become ever shorter. When flying near the Earth its speed will gradually slow down because of atmospheric resistance. To achieve the required decrease in velocity it will be necessary to make many such round-the-world flights, and although no expenditure of fuel is involved here, they are dangerous and fatiguing. It may prove impossible to confine oneself only to aerodynamic braking, especially in the beginning, because of heating up, which may cause the

metallic walls of the ship to melt.

It may be most practical, when landing on Earth, to reduce half of the ship's velocity by using the motor, and the other half by aerodynamic braking. A realistic plan, especially for the beginning, would be to increase the ideal velocity of the space ship at the take-off from the Earth by five-six kilometres per second, bearing in mind the return landing, that is, speaking plainly, by taking along a correspondingly larger amount of fuel.



Trajectory of landing of space ship. Velocity is reduced through braking in atmosphere.

This expenditure of fuel will be reduced to a minimum when, in the future, all or almost all of the braking of the ship will be effected by aerodynamic resistance, which will become possible as science develops, as the phenomena of heat conductivity under the conditions of space travel in the upper atmosphere are studied, when heat-resisting construction materials are produced, and cooling systems perfected. There will be no need to build the entire ship of special heat-resisting materials. It will be sufficient to use these materials only for certain parts of the wing surface.

To make such a landing the ship will need improved aerodynamic forms, which will become possible only when Kondratyuk's idea of a landing glid-

er is used. According to this idea, the space ship, on approaching the Earth, will free itself of all those parts which have become unnecessary and will be converted into a small landing glider, having only a cabin for the crew, wings, and controls. It may be wise to land the ship on the surface of some large water reservoir.

There is every reason for thinking that the commander of a space ship, on approaching the Earth, will be able to land at any point on the Earth's surface. This means that the ship can take off and land at a cosmoport just as airplanes do at an airport. After all, what a pleasant feeling it will be to realize that after having made a "trip" to Mars you will arrive at the very same spot, your very home once more, and there will be no need for anyone to organize special search expeditions to go looking for you all over the Earth!

Chapter 17

A HOP, STEP AND JUMP

A hop, step and jump!... That is one of the most beautiful exercises in field and track, combining strength, agility, grace and exact calculation.

We see a jumper running down a forty-metre track. A push against the pole, and the athlete is in the air. But this is not merely a broad jump. After touching the Earth, the jumper once more pushes off against it. By using the velocity he has accumulated, he seems to fly in the air, moving his legs, waving his arms, stretching forward like a bird. Then again, a third time, the athlete is in the air. This, the third jump, is the final one, and a new record has been set.

What has all this to do with astronautics? Is it possible that the hop, step and jump is the best form of athletic training for future astronauts, according to the latest achievements of the science dealing with space travel?

No, this is by no means the case. True, the idea of a hop, step and jump really does occur to the mind in connection with some of the latest achievements in astronautics, but in this particular case we are not thinking of the physical training of future crews of space ships.

We have already pointed out several times that the most advantageous space flight will be one that is made in stages, with refuelling en route, for which purpose natural or artificial satellites of a planet may be used. And it is easy to understand why such should be the case. If all the neces-

sary fuel were taken on board at the start, a large part of it would be spent on the fuel itself, that is, on the take-off run or braking of this fuel. The situation is quite different if this "excess" fuel is not on the ship.

We can readily appreciate the advantage of this multi-stage method in considering a flight to Mars.

Let us assume that in the beginning our ship, which is taking off from the Earth on its distant journey to Mars, has on board the entire fuel supply necessary for the flight. Let us also assume that the ideal velocity for a round-trip flight from the Earth to Mars, with a landing on Mars, will be 45 kilometres per second. If the jet velocity is four kilometres per second, which we can hope to obtain within the next decade, the required mass ratio of the ship (the ratio of the take-off mass to the ship's mass after all the fuel has been consumed) will be about 76,000, according to Tsiolkovsky's formula. This means that for every ton of weight of the ship itself at take-off there must be about 76,000 tons of fuel. It is impossible, of course, to build such a ship. The maximum possible mass ratio for a multi-step ship can very likely be no more than 150. And so, such a flight to Mars is out of the question.

Let us simplify this task by assuming that there is a community of people living on Mars, and that the production of rocket fuel has been organized there. The ideal velocity of the ship when taking off from the Earth will, in this case, be about one half as much. If this is so, then the mass ratio of the ship at the take-off from the Earth will be equal to only 275 and at the take-off from Mars for the return to the Earth—the same, making a total of 550. Instead of 76,000 tons of fuel per ton of weight of the ship—only 550. What a tremendous difference!

Let us now try to use not only the Earth and Mars to refuel our ship, but also their satellites, the Moon and Deimos. In this case our ship will make a sort of hop, step and jump in space, from the Earth to the Moon, then to Deimos, and finally to Mars.

For purposes of calculation we can take the following values for the ideal velocity: for the round trip, Earth-Moon—16 kilometres per second each way; for the trip from the Moon to Deimos and back—nine kilometres per second each way; and for the round trip Deimos-Mars—six kilometres per second each way. With the same jet velocity of four kilometres per second, the following mass ratios would be required: for the flight from the

Earth to the Moon—55; from the Moon to Deimos—9.5; from Deimos to Mars—4.5; or, for the entire flight:

$$2\times55+2\times9.5+2\times4.5=138.$$

In other words, the flight will require an expenditure of only 137 tons of fuel per ton of weight of the ship, while no more than 54 of these 137 tons will be stored up on the ship at one time.

Even though it is not simple, such a flight is possible, and if, instead of the massive Moon, the Earth should have a small artificial satellite, the effect will be much greater. Such is the advantage of a hop, step and jump in the cosmos. But that is not all.

The entire cosmic route for such a flight is divided up into three sections: the flight in the terrestrial field of gravitation, the flight in the Martian field of gravitation, and that part of the flight which joins these two sections and which is in the solar field of gravitation. This part of the flight is the main one, judged by its duration and distance.

The flying conditions over each of these sections will be different. The reason is simple enough: the force of gravity.

A ship flying over the two extreme sections of the route, that is, when taking off from the Earth or landing on it or on some other planet, will have to overcome its powerful force of attraction. However, when flying over the chief, middle section of the route, where there is only the solar field of attraction, the situation is altogether different. Only the solar attraction affects the ship here. But because of its great distance from the Sun, the attraction towards it will be much less than the attraction towards any other planet when near its surface. When close to the Earth, for instance, the attraction towards the Sun is $^1/_{1650}$ of the attraction towards the Earth.

For the ship it makes a great difference what force of gravity it has to overcome, for this determines the kind of motor to be installed in the ship, the very construction of the ship, and its shape. A ship flying over the extreme sections of the cosmic route will differ greatly from a ship making a flight over the middle section of this trajectory.

But can a space ship change its form in flight, becoming something quite different?

Of course not. It is hardly likely that this could be done. But we can have different ships fly over the different sections of the route. In this case the space travellers would have to transfer twice en route, for which purpose

it would be most feasible to use interplanetary stations, artificial satellites of the Earth and the other planets, as Tsiolkovsky proposed doing.

The passengers fly off from the Earth on one ship, then transfer to another on the satellite; the ship will travel between this satellite and that of Mars. Here, on Mars' satellite, a third ship will be waiting to take the passengers to Mars itself. The reader will no doubt agree that such a journey even more resembles a hop, step and jump by space travellers.

Such a method for making a space flight affords new, quite remarkable, opportunities besides those advantages already mentioned above in connection with using artificial satellites. These opportunities result from the specific features of a flight in the middle section of the cosmic route, in the field of solar gravitation alone.

Whereas a ship flying off from the Earth must have a powerful motor and must be very durable, which means heavy, a ship making a trip between the artificial satellites may be light and may have a motor which develops very little thrust.

The reason for this is obvious. The engine of a ship flying off from the Earth must develop such a thrust that the ship's acceleration will be at least three-four times greater than the acceleration of the Earth's force of gravity. This, in turn, means that the thrust of the engine must be that much greater than the weight of the ship. If the ship, at the take-off, weighs, for example, 500 tons, which is not so very much for a space ship, its motor at the take-off will have to develop a thrust of over 2,000 tons. Naturally, a motor of such a tremendous thrust will have to be very large and weigh very much.

The larger and heavier the engine, the larger and heavier will the ship itself be. But this is not the only reason why the ship, taking off from the Earth, will inevitably be very heavy. The tremendous accelerations during the ship's take-off from the Earth give rise to great forces of inertia which affects the ship. And in order to withstand these inertia overloads the ship must be durable, which means massive and heavy.

The situation is altogether different when the ship takes a promenade between the satellites over the middle section of the route, even though this section is longer. The Sun attracts this ship with a small force which is not very difficult to overcome. The ship's motor may, therefore, have a very small thrust, and the ship itself, not burdened by great inertia forces, may be very light. The shape of this ship, which does not fly in the Earth's

atmosphere, may be any kind. This will considerably facilitate the task of creating artificial weight on the ship, which will very likely prove necessary on this middle section of the route, the very longest.

If the engine of a ship travelling between the orbits of artificial satellites (we may call such a ship inter-orbital) should have a very small thrust and work for a long time (in order considerably to increase the ship's velocity at a small acceleration), the question naturally arises: isn't it possible to use some other kind of jet engine, instead of the liquid-fuel rocket motor? The liquid-fuel rocket motor is known for its ability to develop tremendous thrust within a relatively brief period, which is what makes it especially suitable for ships making flights near the planets. Here the conditions are quite different, which is why the properties of the motor must be different.

Tsiolkovsky, even in his day, considered different types of motors possible for this purpose. Numerous proposals were made after Tsiolkovsky, but they were all usually rejected, for such motors were not suitable for flight near the Earth. The hop, step and jump, as we see, affords great opportunities in this direction.

One of the first thoughts to occur is: cannot the force of pressure of the solar beams be used during the flight of an inter-orbital ship? The existence of this pressure was first established by the Russian physicist P. Lebedev back in 1900. In order to establish the existence of this pressure and to measure it, Lebedev himself performed a most delicate experiment, one which surprised even those who knew of his ability as a brilliant experimenter. The delicacy of the experiment is connected with the very low force of the pressure of light. For instance, the pressure of the solar rays on a sheet placed at right angles to the beam at such a distance from the Sun as the Earth, is equal to half a kilogramme per square ... kilometre! This is a very slight force,* but it nevertheless plays a very big role in nature. The pressure of light deflects the tails of comets from the Sun. It is also supposed to play an important part in the life of the stars, in particular limiting their maximum dimension.

Tsander made calculations showing how we can use the pressure of the solar rays to move space ships in the field of solar gravitation. By using very

* This is the value for an absolutely black body, which absorbs all the rays. In an ideal mirror, which reflects all the rays, the pressure will be double.

thin metal sheets it is possible to equip the ship with mirrors having a tremendous surface and capable of reflecting the solar rays. These sheets of metal may be thousandths of a millimetre in thickness. According to Tsander's calculations, if the surface of such a mirror is 0.1 square kilometre, the mirror will weigh about 300 kilogrammes. However, such a mirror will create a force of only 50 grammes. Under the influence of this force the speed of a vessel weighing 50 tons (on Earth) will increase one-hundredth of a millimetre per second for every second. Obviously, the pressure of the solar rays would not be capable of driving a space ship even if only in the field of solar gravitation.

Since the solar rays that fall on the ship from without are incapable of solving this task, perhaps it can be solved by using the pressure of light rays which are given off by the ship itself? If, let us say, a powerful projector is installed on the ship, the pencil of light rays emitted by it will cause a reaction exactly like that caused by the pressure of a pencil of solar beams falling on the mirror. But even this reaction is too little to create a rocket operating on light. To increase the force of reaction of this pencil of light rays, it is necessary to heat the surface radiating this pencil to a temperature of millions of degrees. This is impossible, of course.

We thus see that in order to create a reaction thrust which will move the space ship, we must absolutely throw something off. The rays have too small a mass for this purpose.

In the usual liquid-fuel rocket motor, as we know, the substance thrown off consists of molecules of gases, the products of the combustion of fuel. If these gases are to be ejected at a great speed, high pressure must be created in the motor. The amount of gases escaping every minute must be great, for otherwise the thrust will be small.

But the engine of an inter-orbital ship must develop a small thrust, as we have noted above. This enables us to use an engine which throws off a much smaller mass than the liquid-fuel rocket engine does, but at a much greater velocity. In order to increase the jet velocity, electric forces can be used instead of pressure force.

For this purpose, for instance, an atomic pseudo-rocket can be used, such as that mentioned in Chapter 8, that is, the force of reaction of the products of atomic disintegration escaping from the motor. The jet velocity of these products can equal tens of thousands of kilometres per second, a speed hardly attainable in any other way.

Another possible jet engine of this type is the electron or ionic engine. The reaction thrust in this motor is created by the escape of particles of a substance which have an electric charge, electrons or ions. These particles are driven to a great speed by means of an electric field which affects them.

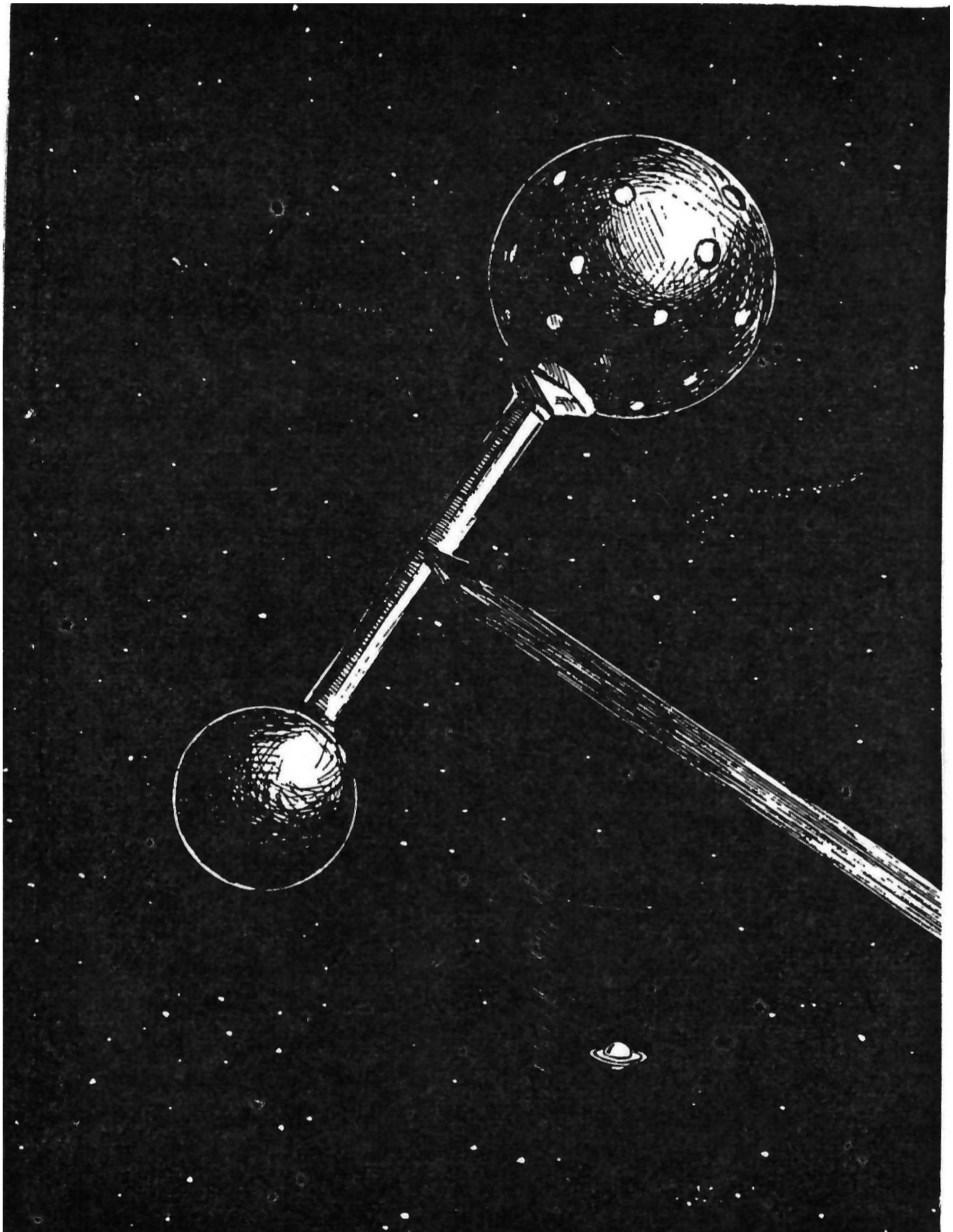
This speeding up of electrically charged particles under the influence of an electric field is widely used in technique. Take, for instance, the ordinary electric current that flows through wires. It is sometimes possible, in special laboratory units, to drive electrically charged particles in this way to tremendous velocities, reaching tens and even hundreds of thousands of kilometres per second.

The idea of an ionic motor is not a new one; it originated with Tsiolkovsky. Such an engine may be built as follows: a powerful electric generator, a dynamo, is installed in the space ship. The energy required to set this generator operating may be obtained by means of an atomic power unit or by catching the solar energy. The electric current produced by the generator is used to charge plates of a gigantic capacitor, which are in the form of thin flat wire gauzes. As a result, a difference in electric potentials is created between the plates of the capacitor and this speeds up the electrically charged particles of the substance, the ions.

Electrons are torn away from ordinary molecules in a special ionization chamber, and we thus get positively charged particles, ions. These ions are then passed between the plates of the capacitor and escape to the outside at a speed of 100 kilometres per second. As they escape the reaction thrust necessary for the ship to fly is created.

This is what the project of an expedition to Mars may be like, when it is made according to the hop, step and jump method, using ionic rockets. This project was developed by the well-known German rocket designer, Dr. Wernher von Braun. The entire expedition can be made on 10 ionic interplanetary ships which are assembled on artificial satellites of the Earth, the parts being delivered from the Earth by freight rockets. A whole fleet of 50 three-step freight rockets will be used to deliver these parts and the crew, for which purpose these rockets will have to make about 1,000 flights. Every such rocket will weigh, at take-off, about 6,500 tons; the first two steps of each rocket will return to the Earth by parachute; the third will glide back to the Earth, for which purpose it will be winged.

The weight of every inter-orbital ionic ship on which the astronauts will reach Mars' orbit will be over 3,500 tons. If three small ships were used,



Ionic space ship for flights in weak field of gravitation.

each weighing 200 tons, 50 people could make a landing on Mars. One of these three ships will remain on Mars, and those fortunates who had visited that planet would return on the other two to their interplanetary armada, which will be waiting for them in the orbit near Mars. Three interplanetary ionic ships and two landing ships will remain in the orbit near Mars, becoming its artificial satellites, while the other seven ships will bring the members of the expedition back to the orbit of the Earth's artificial satellite, whence they will be delivered to the Earth by rockets.

According to calculations, this entire expedition will take about three years and will, of course, require great expenditures. For instance, about five million tons of fuel will be needed for the flights of the freight rockets, while the flight of the interplanetary ionic ships will require about 40,000 tons.

In order to organize such an expedition it will require years (if not decades) of persistent investigation, the joint work of many scientists, designers, engineers, workers, and the solution of most intricate scientific and technical problems. But how great will be the significance of such a victory, a victory of the people in the fight against nature!

Part Five

MAN IN SPACE

Chapter 18

THE UNIVERSE AT THE SERVICE OF MAN

The day is approaching when the Earth's emissaries will set foot upon the soil of the Moon, Mars and Venus for the first time in history. Years will flash by, years full of extraordinary first impressions and the newness of the first discoveries, and then the question will arise: What shall we do with the celestial bodies we have conquered? How can they best serve mankind?

But why wait until then? Surely there is no harm in thinking about that now and evaluating the opportunities afforded by these conquests.

We already touched upon these questions in Chapter 1 and, later, in Chapter 11, in connection with the problem of creating artificial satellites of the Earth. Let us now consider in greater detail the opportunities that will become available to science as a result of the conquest of the Moon, Mars and Venus.

It is not a matter of mere accident that the Moon attracts our special attention. In the first place, it will undoubtedly be the first goal of space travellers, not only because of the relatively insignificant distance between the Moon and the Earth, which makes communication with it very convenient, but also because there are various ways in which the Moon may be used, which are impossible in other cases. And, finally, because we know much more about the Moon than about any other celestial body and can, therefore, judge of the opportunities it offers more correctly than of those afforded by any other celestial body.

Before we can answer the question: "What shall we do with the Moon?" (this, by the way, also refers to the other celestial bodies) we must first of all determine what the living conditions on the Moon will be for those

terrestrial representatives who are sent on this special "mission" to it. Obviously, if these conditions exclude any kind of prolonged sojourn there by people, as would be the case on Mercury, which has a temperature of 400° C. above zero, the possibilities of using the Moon will be greatly limited.

Fortunately, the situation as regards the Moon is not so catastrophic, although it goes without saying that one need not expect terrestrial comforts there. For that matter, there is not a single planet in the solar system which will afford such comfort. Life on the Moon will be rigorous, its nature is hostile to man, and he himself will have to procure everything necessary for his existence there.

The most decisive factor is the absence of an atmosphere on the Moon. Man will, therefore, have to wear a suit isolating him from the surrounding space. This suit may be the usual astronautic space suit of the "swimmer" we mentioned above, or it may be more intricate and with greater improvements. In any case, such a suit will be a most cumbersome arrangement. Compared with this, the armour of mediaeval knights will seem most graceful wearing apparel. The relatively heavy weight of the suit will not be an obstacle since weight on the Moon is only $^1/_6$ of that on Earth. A terrestrial centner will be only 16 kilogrammes on the Moon. Since a person weighing 60 kilogrammes on Earth will be "lightened" to only 10 on the Moon, then, even if he wears a suit weighing 150 kilogrammes, the total weight of the man and the suit will be only 35 kilogrammes on the Moon. In other words, even under this condition man will feel only half as heavy on the Moon as he does on Earth. True, his mobility is determined not only by his weight but also by his mass, whose inertia must be overcome. For instance, while a hammer on the Moon will weigh only $^1/_6$ of what it does on Earth, it will be just as difficult to brandish. That is why people, enclosed in their cumbersome, massive suits, will of necessity conduct themselves most staidly on the Moon and move about slowly; at any rate, they will not be able to make acrobatic leaps 20 metres in length and five metres high, as certain authors are inclined to think they will.

The organization of a community on the Moon will be fully possible, although it will involve considerable difficulty. The space ships which brought the people to the Moon will serve as their first dwellings. Then special lunar tents will be assembled for them, made of super-durable plastic materials. It will probably be desirable to build permanent dwellings below the surface of the Moon, "sublunar" residences (compare with our "subter-

ranean"), if it would be possible, of course. This would be desirable from the point of view of heat-isolation, hermetic conditioning, expenditure of building materials, protection against the harmful influences of world space, etc. Gradually entire sublunar cities could be organized beneath the Moon's surface.

The people on the Moon will be provided with everything they need from the Earth, at least in the beginning. The Earth will supply the air necessary to breathe, food, water, and all other vital supplies. Later the lunar colony will learn to "take care of itself."

Numerous hot-houses and hot-beds may supply oxygen, vegetables and fruit. Oxygen will also be obtainable from the lunar soil. For instance, about 50 per cent of the terrestrial crust consists of oxygen.

Many minerals on Earth contain water. It is likely that water will also be obtainable on the Moon.* It is quite possible, too, that there is ice at the bottom of the deepest hollows.

The chief food products will later be obtainable synthetically. Then, too, livestock farms may be organized. Thus it will be possible to procure everything necessary for life on the Moon.

In order to enable people to "get places" on the surface of the Moon, electric transport may be used, as the electromobile, later—electric trains, or thermal engines (gas-turbine or jet) which will operate on rocket fuels. Aviation would be very helpful on the Moon because of the unevenness of the lunar surface. However, the absence of air makes the usual form of aviation impossible. Flying machines may be used for this purpose, of the type which are equipped with rocket engines that serve not only for the take-off run, but also for support in the air, to create lift.

Contact among the lunar inhabitants may be effected via radio. In order to increase the radius of such radio communication, which is very small because of the sharp curvature of the lunar surface, every space suit will have to be supplied with the highest possible antenna. Without this, radio communication will extend no more than two-three kilometres; an antenna of 15 metres will increase this radius to 10 kilometres. To conduct a conversation in person, an apparatus similar to the laryngophone, used by pilots during flights, could be used.

* The cliffs of volcanic origin, which occupy the greater part of the lunar surface, contain up to five per cent of water. Water has also been discovered in meteorites.

When we speak of using the Moon and the planets to serve man, we have three possible forms of such service in mind: scientific, industrial, astronautical.

It is indeed difficult to overestimate the scientific significance of the first lunar colony. It would provide astronomers with an observatory such as they can only dream of at present. We have already spoken of the advantages of an observatory on an artificial satellite. An observatory on the Moon would be even more valuable. For instance, it would not suffer from the defect of an observatory on a satellite caused by its relatively small mass and subsequent great mobility. An incautious movement on the part of the observer might, on such a satellite, completely change the position of the telescope. This is of vast importance when making photographs with long exposures. And there, beyond the terrestrial atmosphere, such photography, which is so valuable in astronomy, will be possible, and one will be able to photograph in this way as much as one likes. On Earth the dispersed light, even on the darkest of nights, illuminates the photographic plate during a long exposure, which, therefore, makes it impossible to get pictures of weak nebulae, distant stars, etc. Furthermore, certain observations of stars and planets, which we are unable to make on Earth, will become possible because of the long lunar night, which lasts two terrestrial weeks.

The study of cosmic radiation will be organized on quite a new basis. Physicists, chemists, biologists, physiologists, doctors and others will be able to make very valuable investigations on the Moon.

The Moon itself, including its mysterious "other" side, will, of course, be subjected to a most detailed study. And it will finally become possible to answer numerous questions which have been bothering scientists engaged in a study of the Moon. An important contribution will be made to the study of the planets. This will become possible because lunar telescopes will have much greater magnifying power and will be capable of giving incomparably better images than those obtainable in the best terrestrial observatories. It will thus be possible to obtain ideal photographs of the planets. Furthermore, a visit to the Moon will enable the astronomer to make a more critical analysis of many methods of observation and the study of the planets, now used in astronomy (both by checking up on the correctness of terrestrial observations of the Moon and by lunar observations of the Earth). The chemical composition of the substances that go to form

the lunar surface will at last be fathomed. So far, despite the proximity of the Moon, scientists know absolutely nothing about this, whereas the composition of the stars, that are thousands of millions of times farther away, is well known, thanks to the light these stars themselves radiate.

Observations of the Earth will provide much valuable material for geographers and meteorologists. A visit to the Moon will tell geologists a great deal about the processes of the formation of the Earth, the influence of atmospheric phenomena on the Earth's surface, etc. For instance, the deep pits on the Moon would make it possible to judge of the structure of the deep strata of the Earth's crust, for, according to a hypothesis formulated by Academician O. Schmidt, the processes of the formation of the Earth and the Moon were similar. To be able to make such conclusions on Earth it would be necessary to dig pits from 10 to 15 times deeper, which is hardly possible.

Briefly, the Moon will, in the future, become a most extensive laboratory, and this lunar branch of the Academy of Sciences will supply invaluable scientific information.

The possibilities of using the Moon for industrial purposes are most fascinating. Mines may be sunk on the Moon to procure many valuable minerals and metals,* chemical plants may be put up to produce various chemicals, including certain rocket fuels (as hydroborons), and other enterprises may be built. Tremendous solar power plants may be erected, to supply the energy required by all this lunar industry. This would be possible because of the absence of a lunar atmosphere.** It will also be convenient, later, to build powerful atomic electric and thermal stations on the Moon. The absence of an atmosphere on the Moon and the great curvature of the lunar surface may make such stations, if properly located, safe even without any powerful protective screening, which is necessary on Earth for protection against the harmful radioactive radiation of atomic

* According to certain hypotheses, the heavy metals which are contained in meteoites may be discovered right on the surface of the Moon.

** Theoretically it will be possible, by using solar heat, to obtain from one hectare (2.5 acres) of lunar surface 15 thousand kilowatts of energy. However, solar stations will be able to operate on the Moon only during the two-week "day," and it will, therefore, be necessary to build a ring of such stations, located at great distances from each other, so as to ensure an uninterrupted supply of energy obtainable from the Sun.

reactors when operating. These stations will have to be controlled, of course, telemechanically, from a distance.

The output of lunar plants will not only be used to satisfy lunar needs, but will also be delivered to the Earth. The escape velocity from the Moon is only $2^1/_3$ kilometres per second, that is, in order to escape, the ship will require a bit less than of $^1/_{20}$ of the kinetic energy necessary on Earth. Thus, a relatively very small expenditure of fuel will be needed to transfer goods in this way. Needless to say, this fuel should be produced on the Moon itself.

The possibilities of using the Moon astronautically, of converting it into a sort of "window into the cosmos," are exceptionally great. The Moon will not only be the first goal for space travel, but it will be a training centre of tremendous importance when getting ready for distant space flights, for training astronauts, testing ships, apparatus, etc. There will probably be a permanently functioning "training camp" on the Moon, belonging to the Higher Astronautical School, where future astronauts will perfect their theoretical and practical studies.

If it should be possible to organize the production of rocket fuel on the Moon, this satellite will play an important part as an intermediate station for distant interplanetary ships. The organization of such production will probably be the most important and primary task of the people on the Moon. And there can hardly be any doubt that this task will be solved. A contributing factor is the abundance of energy resources on the Moon. Water will be produced to supply the working fluid for atomic jet engines; for chemical liquid-fuel rocket engines it will be possible to organize the production of liquid oxygen, various metallic hydrides, that is, compounds of metals and hydrogen, silicon hydrides, and other combustibles.

By no means will it be absolutely necessary for space ships to land on the Moon in order to refuel. For this purpose the ship need only become a satellite of the Moon for a while, in order to intercept the container of fuel sent from the Moon to the corresponding orbit. It will also be possible to use an artificial satellite of the Moon, as proposed for this purpose by Kondratyuk. Large quantities of fuel supplied from the Moon may be accumulated on this satellite in advance. The circular velocity in relation to the Moon, near its surface, is equal to 1.7 kilometres per second, so that a missile fired from a modern long-range gun set up on the Moon can become a permanent lunar satellite.

It will also be feasible to supply terrestrial satellites with fuel from the Moon. This will require slightly more fuel (about 20 per cent more) than if it were sent to a lunar satellite. Incidentally, it may be practical to build, right on the Moon, interplanetary stations to be set up at the Earth's shores. They can then be transferred from the Moon to their orbits near the Earth.

The specific features of the Moon, its low escape velocity, the absence of an atmosphere, and its great supply of energy, make it feasible to send freight to the lunar and terrestrial satellites and also to the Earth itself not by rocket but by an electromagnetic catapult. Generally speaking, if regarded from the viewpoint of energy expenditure for the take-off run of a space projectile, such a catapult is more practical than a rocket. In any catapult energy will be spent only on the take-off run of the ship itself, whereas in the case of a rocket take-off the larger part of the fuel that is consumed is spent on the acceleration of that very fuel, whose mass is so many times greater than the mass of the ship. However, the use of catapults for the take-off of manned space ships is out of the question because of the limitation of the allowable acceleration. This would necessitate having a catapult many hundreds of kilometres long. The situation is altogether different as regards launching freight ships with fuel, goods, raw materials. In this case the accelerations may be very great and the length of the catapult correspondingly much less.

In an artillery gun the acceleration of a projectile when fired may be tens of thousands of times greater than the acceleration of the Earth's gravity. However, even with much smaller accelerations it is fully possible to build electromagnetic catapults, especially on the Moon, where the required final velocity of the ship is much less than on Earth.

The absence of an atmosphere on the Moon does away with another obstacle as regards using catapults, an obstacle which exists on Earth—overheating the ship during the take-off run. When a ship is launched by catapult from the Earth, it must fly in very dense air at a tremendous speed, with the result that even in the best of cases the ship's skin will suffer greatly because of aerodynamic overheating. Theoretically, the temperature may rise to many tens of thousands of degrees, as a result of which the ship's skin will evaporate instantly. The only salvation for the ship is its speed—it must pierce the dense atmosphere instantly and make off to such altitudes where there will be no overheating. In a word, the

terrestrial atmosphere makes it impossible, in practice, to launch a ship by catapult. This obstacle does not exist on the Moon.

The electromagnetic catapult for the take-off run of a ship will be built on the same principle as that governing the construction of all electric machines, generators and motors, which play such an important role in modern technique. Physics tells us that when an electric conductor moves in a magnetic field, an electric current arises in that conductor. That is exactly how dynamos, the generators of electric current, are built. On the other hand, if we force current to flow through the conductor which is in the magnetic field, the conductor will begin to move about in that field. This phenomenon is used in the building of electric motors. In the dynamo mechanical energy (the rotation of the armature) is converted into electrical energy; in the electric motor, on the other hand, electrical energy is converted into mechanical.

Obviously in the case under discussion we must apply the principle of electric motors, inasmuch as mechanical work, the take-off run of the ship, that is, imparting to it the necessary kinetic energy, must be accomplished by the electric energy expended.

We can visualize the catapult as follows: a powerful magnetic field is set up between the flat polar shoes of the electromagnets. The flat armature of the catapult can move about in this field. When current begins to flow in the armature winding, the armature begins to move along the polar ends of the electromagnet. The ship that is taking off is connected with the armature. Such catapults are already being used today to launch aircraft.

According to one project for such an electromagnetic catapult it would be possible to send freight tankers containing one ton of fuel off from the Moon every several hours. This fuel would be stored up on a lunar satellite and later used to refuel space ships. Such an arrangement would be of tremendous importance for the future of interplanetary communication. This alone would justify the organization of a colony on the Moon.

The plan for the conquest of the Moon, outlined in such general terms above, is a task that is calculated for many decades.

The living conditions on Mars will very likely be easier than those on the Moon. It will be possible to obtain oxygen from Mars' atmosphere, although it is very rare: its oxygen content is supposed to be less than $^1/_{1000}$ that of the Earth's. Water is also present both on the surface of Mars and in its atmosphere, although, once again, in very small quantities.

Plant life exists on Mars. The temperature on this planet does not drop below —70° C.,* which is the same as on Earth. However, it will not be possible to get along without a space suit on Mars, for the atmosphere is too rare and the pressure on Mars corresponds to terrestrial altitudes of 16-17 kilometres.

The scientific findings of an excursion to Mars should be exceptionally valuable. It will at last become possible to solve Mars' numerous mysteries, which have been worrying the minds of scientists and inspiring the imagination of writers.

What fascinating opportunities scientists will have when they are able to visit Mars! How enriched will our knowledge become, and what progress science will make!

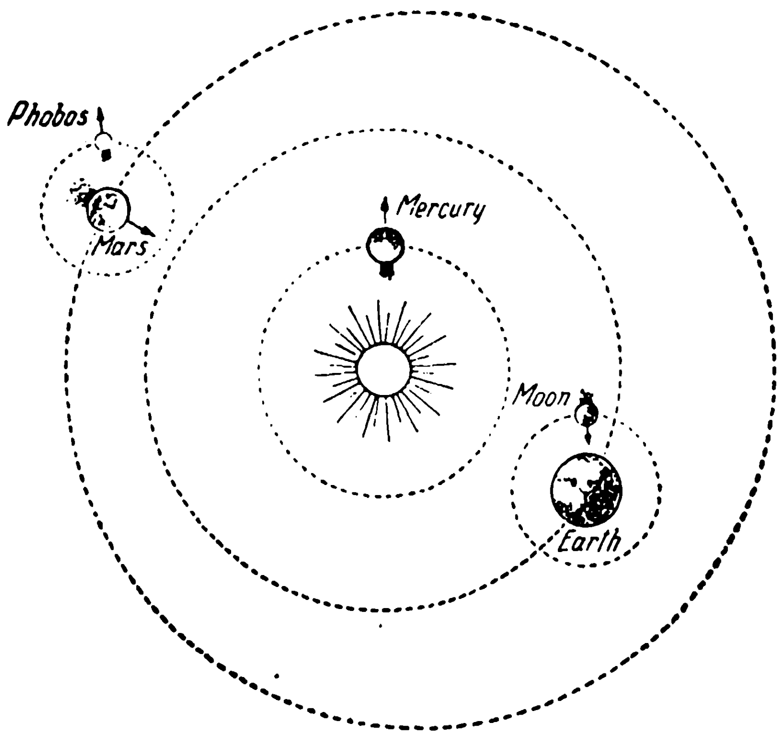
It will be possible to organize colonies of people on Mars, similar to those on the Moon, and industrial enterprises as well. The relatively great distance of Mars from the Sun will make it impractical to use solar energy, and the chief source of energy on Mars will, therefore, probably be atomic power stations. The astronautical significance of Mars may prove very great when space flights of the third stage, those to the outer planets of the solar system, are undertaken. We may assume that long-distance space ships will be refuelled from Mars. It is most likely that this fuel will first be stored up on Mars' satellites, Phobos and Deimos. For this purpose the production of rocket fuel will have to be organized on Mars.

Scientists know very little about the Earth's mysterious neighbour, Venus. The impermeable layer of clouds that constantly envelop this planet very effectively conceal all her secrets. Venus has a dense atmosphere** about whose composition we know very little. The only thing we can consider as having been definitely established is that it contains much carbonic acid, much more than the Earth's atmosphere has. Practically no oxygen has been discovered in Venus' atmosphere, while its water content is not more than $^1/_{10}$ that of the Earth's. It should be noted that all these con-

* Temperatures of —100° C. have been observed at the Martian poles.

** Venus' atmosphere was discovered by Lomonosov in 1761. This brilliant discovery laid the basis for the physical study of the planets. Lomonosov considered the study of the planets and their satellites not as a goal within itself, but as a basis for the study of problems of greater ideological significance, in particular, the problem of the habitability of other celestial bodies.

clusions have been made on the basis of data obtained by a spectral analysis of the gases that lie above the stratum of certain opaque clouds. The composition of these clouds and the gases beneath them is unknown. That is why nothing definite can be said about the living conditions on Venus, except, perhaps, that the temperature on its surface may reach 100° C. Obviously only the landing of a cosmic ship on the surface of Venus will be able to solve these mysteries.



"Reconstruction" of the solar system.

Much more could be said about the opportunities that will be afforded people as the space ships on which they are travelling make their way deep within the solar system, farther and farther from the Earth, and when landings on ever new celestial bodies are made. But even the little we have mentioned above, which will become possible after the first victories of astronautics, will be of such great importance for the future of the scientific technical progress of mankind, that the desirability of directing our efforts towards interplanetary flight is quite obvious.

We cannot, today, foresee all the opportunities that may become available as the science of astronautics is further developed and achievements in it are attained.

For instance, usually no mention is made of the possibility, one which exists in principle, of man's active interference in the life of the solar system. By using jet technique, especially atomic reaction technique, we will be able, at wish, to change the paths of motion of the celestial bodies in their orbits and reorganize the solar system.

To change the course of any particular celestial body, it will be neces-

sary to set up a powerful battery of jet engines on it, such as operate on atomic or chemical fuel, and to switch on these engines at very definite moments. At the present level of development of reaction technique it would be possible to change the path of only relatively small celestial bodies. Although the Moon is not so small, yet its course about the Earth could be changed at will even today.

In order to achieve this, the molecules of gases escaping from the liquid-fuel rocket motors set up on the Moon must have a greater velocity than the velocity of escape from the Moon, which, as we know, is equal to $2^1/_3$ kilometres per second. They would then part with the Moon for all time, shoving it away from the orbit in which it revolves around the Earth.

By affecting the lunar orbit in this way it may become possible, some day, to render a great service to man, that is, to prevent the Moon from falling on the Earth, which might become possible in the very distant future (if the views of certain scientists who have expressed such a hypothesis should turn out to be correct). This would take place, in any event, not before many thousands of millions of years had elapsed.

We could suggest many other ways in which man could usefully interfere in the well-regulated life of the solar system. However, we shall leave it to future generations to think them out, for they will have plenty of time to do so.

Chapter 19

ON A SPACE SHIP

What difficulties and dangers await the future space travellers when they find themselves face to face with interplanetary space? Will man be able to hold out against all the trials he will experience during space travel?

The answers to these questions may prove decisive as far as the future of astronautics is concerned.

Today it is as yet impossible to give a very definite reply to them. In order to do so, one must make numerous, diverse investigations in the laboratories of scientists and by means of experimental flights of high-altitude rockets. As with other physiological problems, these experiments, too, will first be made with animals.

Such investigations are already being made today. Animals, for instance, are sent up in stratospheric rockets. People will be permitted to

undertake such flights only later. The final result will only be known after the first long cosmic flight has been made.

For the time being we can judge of the dangers of interplanetary travel only in a preliminary way, basing our findings on the knowledge now available in various fields of science. Fortunately, as we shall see later on, such a preliminary estimate does not give us any reason for assuming that an interplanetary flight will be impossible because of man's inability to stand up to it. Although the various dangers awaiting man in space are very serious ones, they can probably be obviated. Tsiolkovsky, who was the first to consider the different dangers of space travel, also came to this conclusion, which is confirmed by the latest investigations.

When man has finally dared to penetrate space, he will find it hostile to him in every respect. What dangers and difficulties will the traveller in this boundless "ocean" not encounter! Absolutely no air, severest cold, scorching solar rays, other rays that are harmful or even fatal, boundless expanses and a flight that lasts for months, collisions with celestial stones, the complete disappearance of weight and at times, on the contrary, its inordinate increase, and who knows what else!... Everything must be studied and weighed before a space ship takes off on its distant journey, for any mistake, even the most insignificant, may prove fatal for man in his hand-to-hand encounter with the elements.

The only thing capable of saving man when he decides to invade the expanses of space, which are so full of danger, will be his complete all-round protection against all the possible influences of that space. Those astronauts who undertake an interplanetary journey will be subjected to long, voluntary confinement in a space ship, which may often last many months. And all they will have to count upon will be their own courage, ability, and such supplies as they have with them.

Many are the things the commander of a space ship will have to bear in mind when he fits it out for that long and difficult trip.

First of all, there is the air. The passengers will have to breathe fresh clean air all the time. This means it will be necessary constantly to expel from their cabin the poisonous carbon dioxide which they exhale, and, on the other hand, to procure oxygen in place of that which has been absorbed. How is this to be done? What oxygen supplies are necessary? What is the best air pressure to be maintained in the ship? These are questions which must be answered first of all.

It will probably be desirable to maintain such a pressure in the passenger compartment of a space ship, as will be slightly less than the usual atmospheric pressure at the surface of the Earth, such, for instance, as at some high mountain resort. That will lessen the load on the walls of the compartment and will simplify the whole air-conditioning system. Incidentally, this question will not be of great importance, and the experiences of the first flights will supply the final answer to it.

The air pumped out of the cabin will be delivered by a ventilator to a purifier, which will rid it of its carbon dioxide. Chemical methods of purification may be used, but it is also possible that a refrigerator will be employed, one in which "dry ice" is formed, that is, where the carbon dioxide is frozen. In this case it must be borne in mind that the water vapours in the air will be condensed in this refrigerator, becoming water, which will then freeze into ice; if this water is not used (not regenerated), it will later have to be supplemented from the supplies on board the ship, but we must not forget that this water comprises about 60 per cent of all the water used by the passengers of the ship.

The addition of oxygen to the air freed of carbon dioxide will take place in a gasifier, in which liquid oxygen, kept in oxygen containers on the ship, will be converted into gas. Then the air is passed into a moistener in which the content of moisture in the air is increased to the required amount. The next step will be to enrich the air with all the necessary aromatic and other substances, for which there will be a special apparatus, and, finally, it will be passed through a heater in which it will be heated to the required temperature. When all this has been done, the ventilator will supply the freshly prepared air to the passenger compartment.

The needed amount of oxygen in the ship will be determined by the number of passengers and the duration of the flight. It is no simple matter to calculate what this amount will be, inasmuch as the amount of oxygen used by man depends on many conditions: the intensity and character of the work he does, the length of time he sleeps, etc. For preliminary calculations we can assume that every passenger on the ship will, on an average, consume no more that one kilogramme of oxygen per day, bearing in mind that he moves about relatively little on the ship. So we see, there are no particular difficulties connected with the problem of supplying oxygen for flights over relatively short distances. For instance, for a trip to the Moon and back, on a ship carrying three passengers, the oxygen supply need be

only 20-25 kilogrammes. This problem is especially simplified if the ship's motor uses liquid oxygen as an oxidizer.

However, the situation changes if the flights cover greater distances. Thus, on a flight to Mars, which lasts about nine months, each passenger on the ship will require a supply of about 300 kilogrammes of oxygen, and then only providing that the oxygen required for life on Mars and for the return trip will be obtained from Mars' atmosphere. Obviously, in cases of such long-range flights it will be necessary to organize a laboratory on board the ship to produce oxygen for the passengers of the space ship. For instance, it is possible to build such a unit in which the carbon dioxide exhaled by the ship's crew will be split up again into carbon and oxygen, for which purpose, of course, it will be necessary to expend a corresponding amount of energy. This apparatus will "breathe" just as plants do: it will inhale carbon dioxide and exhale oxygen. True, this comparison with plants is a superficial one. Soviet scientists have in recent years discovered that the oxygen given off by plants comes not from carbon dioxide but from the water which the plants suck up through their roots.

A matter of no less importance than that of supplying the passengers of the space ship with oxygen is the satisfaction of their needs as regards food and water. Food specialists will have a great field of activity awaiting them. They will have to prepare the most diverse assortment of foods for the needs of the astronauts. The experience accumulated in the organization of polar expeditions and also long-range aviation flights will be of definite value here. However, that is but a timid beginning. Similar tasks connected with the organization of interplanetary trips will be immeasurably more complicated.

It is difficult to determine exactly what supply of food and water should be taken along on a space ship. Just as an approximation we can say that the minimum supply of water per person should be about one kilogramme a day, bearing in mind that the water contained in the air (exhaled during breathing and given off through the skin during perspiration) will be extracted from it and used again, for the total water requirements of man are about 2-2.5 kilogrammes a day. The supply of food can be determined on the basis of 0.5-1 kilogramme per man a day. It follows, then, that the daily requirements of oxygen, food and water for each passenger of a space ship will be about 2.5-3 kilogrammes, but to be on the safe side it would be best to take the higher figure. This should be considered when the ship

is being designed and when the necessary amount of fuel and the like are being determined.

The ship should have a special heating system to supply the passengers with heat, that is, to maintain the necessary temperature of the air in the compartment. When this is done, measures must be taken to ensure the thorough thermal isolation of the cabin, for the ship's heat will hardly be sufficient to warm up the space around it.

The Sun can, in practically all cases, be the source of heat. Solar boilers, which will heat the liquid that will circulate in the heating system of the cabin, will be located on the surface of the ship for this purpose. It will obviously be possible to use one of the components of the engine fuel for this liquid, the oxidizer or the combustible. The surface of the boilers will be painted a dark colour to better absorb the heat of the solar rays. The boilers may be protected with folding covers at the take-off of the ship and also when they are shut off. These folding covers, like the rest of the ship's surface, will possibly be painted with a metallic paint, perhaps pulverized aluminium, which will give the ship a pleasing silvery colour. This will be of value in diminishing the absorption of solar rays and the irradiation of heat by the ship. On long flights to the outer planets the boilers can be better heated by reflecting mirrors that open up.

If the ship has an atomic engine, the problem of heating is greatly simplified, and it will not be necessary to resort to solar energy for this purpose.

It should be pointed out that the heating system for the cabin may be used at will as a cooling unit, to cool instead of heating. This may become necessary during certain interplanetary flights in the direction of the Sun.

The isolation of the space travellers in the ship will not end when the ship lands on some planet. Only after the conditions existing on the planet will have been thoroughly studied will the passengers be able to climb out beyond the protective walls of their ship. In all cases they will be able to leave the ship only when clad in space suits which will vary according to the different planets.

One of the serious dangers which may be lying in wait for man on the celestial bodies may be bacteria that are unknown to us on Earth and which may be fatal for man inasmuch as our organism has not been adapted to combat them. What may prove even more dangerous will be such bacteria as are brought back to the Earth from some distant world by the space ship. Undoubtedly the space ship and its passengers will have to

undergo the strictest quarantine on their return to the Earth. It will be a pity, needless to say, to deprive the space travellers of the company of people after they have spent so many months and, perhaps, years beyond the Earth, but the possible danger to all mankind is too great to permit any careless lack of caution.

Chapter 20

DO WE NEED OUR WEIGHT?

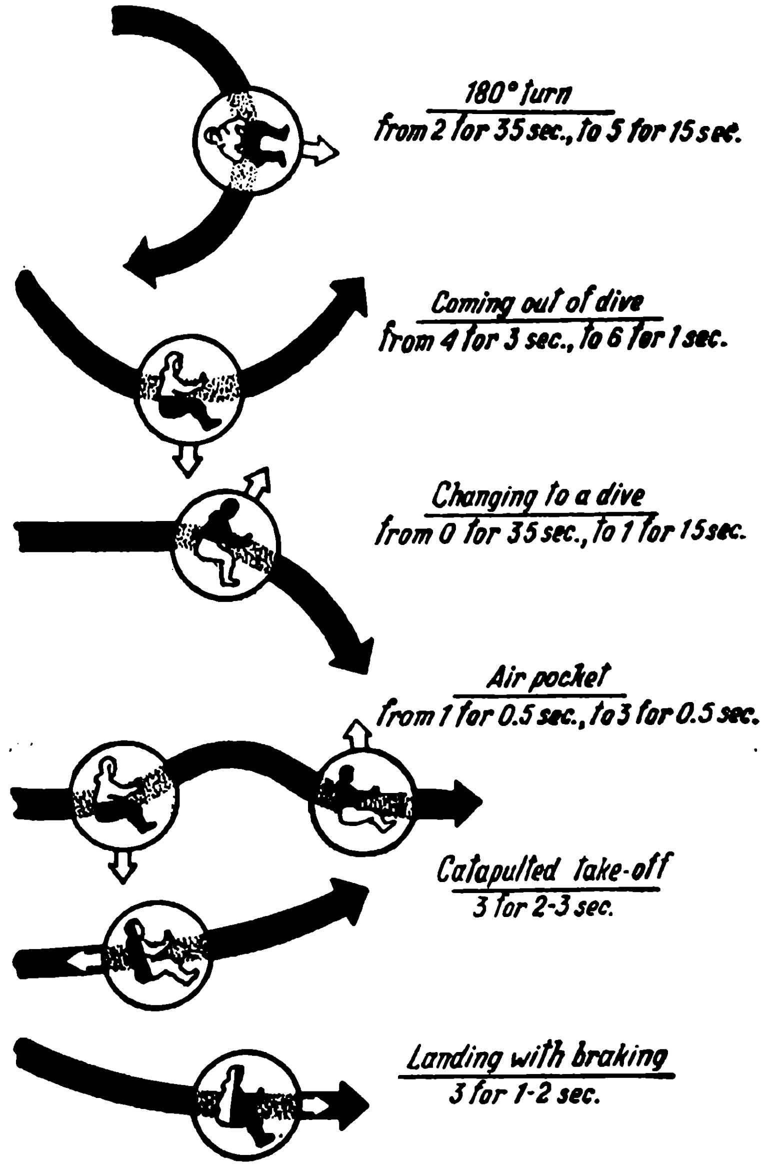
We are so accustomed to our weight that we usually are not even aware of it except, perhaps, when the doctor advises us to put on some weight or to get rid of some. And so the question, "Do we need our weight?" may, at first glance, seem a very strange one.

Indeed, every person on Earth has weight, and weight that is, on the whole, quite constant, stable. Alas, the situation is quite different in astronautics. When flying in space your terrestrial weight of 50 or 60 kilogrammes may, in the beginning, be increased threefold, and you will thus break all existing "records"; then you may instantly lose not only all you have acquired but even the weight you started out with, becoming as light as a bit of fluff. Such impetuous changes in weight compel us to pause and consider more attentively the role weight plays in our life. Can these changes in our weight interfere with the important vital functions of the human organism?

Our weight is the force with which the Earth attracts us. When we stand this force presses the soles of our feet to the Earth, our whole body presses down on our feet, our internal organs press one upon another, our head on our neck, etc., and all of these pressure forces create the physiological sensation we call weight.

The processes that take place during the take-off run of the vessel and also when braking during the ship's landing, cause a considerable increase in weight. The inertia overloads that arise at these moments may greatly increase our weight. Because of the harmful physiological effect of increased weight, the inertia overload should not be more than four, that is, the weight when such overloads exist should not be over four times the normal weight. But why exactly fourfold? Inasmuch as an increase in the inertia overloads might mean a substantial saving in fuel, there must be a sound reason for selecting the value of the allowable overloads.

How is the harmful effect of increased weight manifested? Just imagine that the lids of your eyes become many times heavier and they seem to be "loaded with lead," as we say when we feel we just cannot stay awake. In this case the strength of the eye muscles may prove insufficient to keep the lids open and willy-nilly they close. You feel you are becoming blind, you cannot see a thing. That is what happens to fliers of planes during stunt flying. For an instant, as when coming out of a steep dive, they completely or almost completely lose their sight, which may sometimes prove fatal. This is only one illustration of how increased weight makes itself felt.



Inertia overloads acting on pilot during flight.

Much more serious is the effect of the displacement of the internal organs under the influence of increased weight, for such changes may greatly affect the most important functions of our organism. Usually an increase in weight beyond the allowable limits not only causes mechanical injury to the internal organs, but it also interferes with the work of the heart and the brain. The blood becomes that much heavier and the heart is unable to handle its greatly increased burden. A person may lose consciousness because of insufficient blood in the brain, which sometimes happens with pilots who have to increase the allowable inertia overloads, as during a battle. The heart may fail to hold out, especially if there is anything

wrong with it. It is, therefore, no wonder that ideal health and physical training are demanded of fliers. One and the same overloads affect different people differently.

Of great importance is the duration of the overload. A person may withstand very great overloads during brief periods. We are chiefly indebted to aviation for the experience accumulated in this connection. And so we may assume that a person can hold out under an overload not exceeding two, that is, when his weight is increased twofold, for a rather long time. An overload of four (in this case a person's weight will be about 200-250 kilogrammes), which is accepted as the allowable overload during the take-off of a space ship, can probably be endured for several minutes without serious interference with the functions of the organism.* People can hold out for fractions of a second under an overload of 15 and even 20, in which case they may "weigh" over a ton. Such overloads are experienced, for instance, during dives, at the very moment when the diver enters the water.

Tsiolkovsky proposed a special apparatus, which is now being used, to investigate the effect of great inertia overloads on the human organism and to train fliers. For instance, a long rail track down which a cart in which a person is seated is driven by means of a rocket motor. This cart is stopped suddenly to produce an overload. During some tests with such an apparatus, a person was able to hold out under an overload of 35 for $^{1}/_{5}$ of a second. For the same purpose one sometimes uses a sort of carrousel centrifuge consisting of a lever, from 15 to 20 metres long, with a seat for a man or a testing cabin attached to one end. The centrifuge is made to rotate about its axis by means of an electric motor. Such a unit makes it possible to produce practically any desired overload for an unlimited period, the overload being created by centrifugal force during rotation. When tests were made with various animals an overload of many times ten was attained. Such units will undoubtedly be used to train astronauts in the future.

It is quite simple to understand why a person in different positions reacts differently to an overload. The flow of blood from the brain or, on

* The motor-cyclist who takes part in the well-known stunt of "motor-cycle races along a vertical wall" is subjected to an overload of this kind. The motor-cycle rushes along a vertical wall of a cylindrical shaft, that is, in a horizontal position. Stunts of this kind usually last several minutes.

the contrary, to the brain, and the load on the heart during inertia overloads depend on the weight of the "column" of blood affecting these organs, which, in turn, is determined by the height of this "column." Overloads, therefore, affect a standing person more seriously than any other. When a person is seated he can endure much greater overloads, especially if these overloads come from the head. He can hold out under the greatest overloads when he is in a horizontal position. This explains why, when the first jet planes appeared and greater overloads developed because of the great velocities during flight, the designers began trying to place the pilot on his abdomen or back. This also enabled them to decrease the transverse section of the fuselage of the plane, which led to a decrease in the frontal resistance and an increase in the flight speed. However, the pilots did not like this horizontal position very much, even though it enabled them to endure the inertia overloads when doing stunt flying. Today the situation is different. The pilot is seated in a so-called anti-overload or contour chair. When the plane is immobile or the overload is small, as during a horizontal flight or when taking off, the pilot sits in this chair as in an ordinary chair. If the overload is increased, the back of the chair automatically drops backward and the greater the overload, the farther back it falls. When the overloads are great, the pilot almost lies flat on his back.

Passengers on a space ship will probably be seated in similar chairs or may even have to lie on their backs from the very beginning. The chairs for the passengers will have to be sufficiently springy to accommodate the bodies of the persons lying in them. That will make it easier for the passengers to endure the load on them.

Tsiolkovsky even thought of placing the passengers, at the take-off of the space ship, in a hydro-shock-absorber, a vessel filled with a liquid that had an especially selected specific gravity, equal to the specific gravity of the human body. Inasmuch as a body immersed in a liquid loses as much weight as the weight of the displaced liquid, the passenger seated in this type of bath would weigh nothing at all, and in this case he need not fear any overload whatever. *

It is quite possible that special anti-overload suits such as are used in aviation today will be used in astronautics. Air is insufflated between two

* The internal organs of the human body might nevertheless be displaced as regards their relative positions.

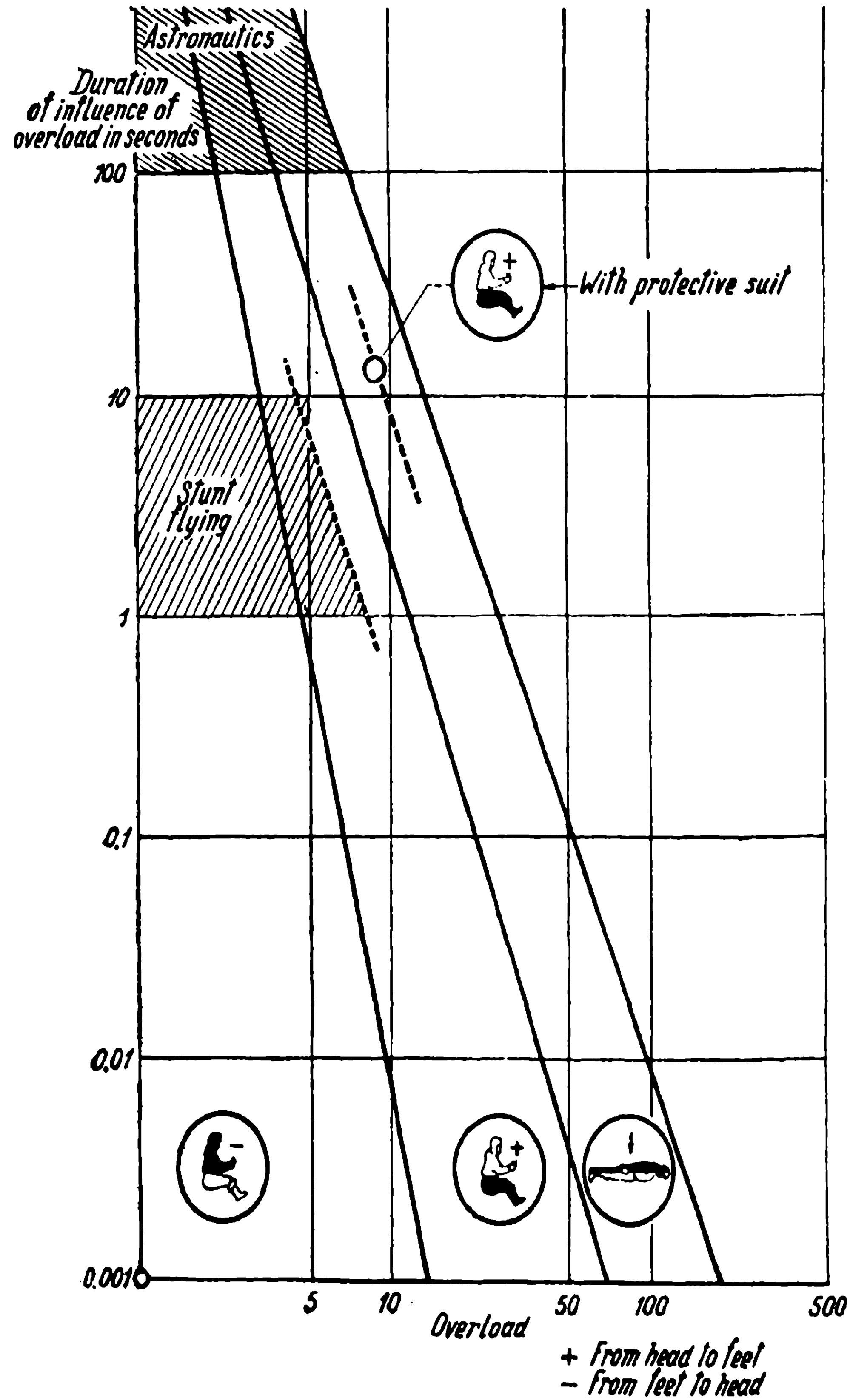
layers of the fabric of such a suit, so that the inner layer lies close to the body of the pilot.

These overloads might prove critical if it were necessary to make a long gradual take-off and a similar landing. However, as pointed out above, when the overload is four, the take-off will last no longer than 6-7 minutes, during which the passengers of the ship will probably be able to hold out without extreme unpleasantnesses. Even when the overload is reduced to three the duration of the take-off will be increased to only eight minutes. Thus the dangers connected with the effect of overload at take-off, so often spoken of in the past, are most likely exaggerated.*

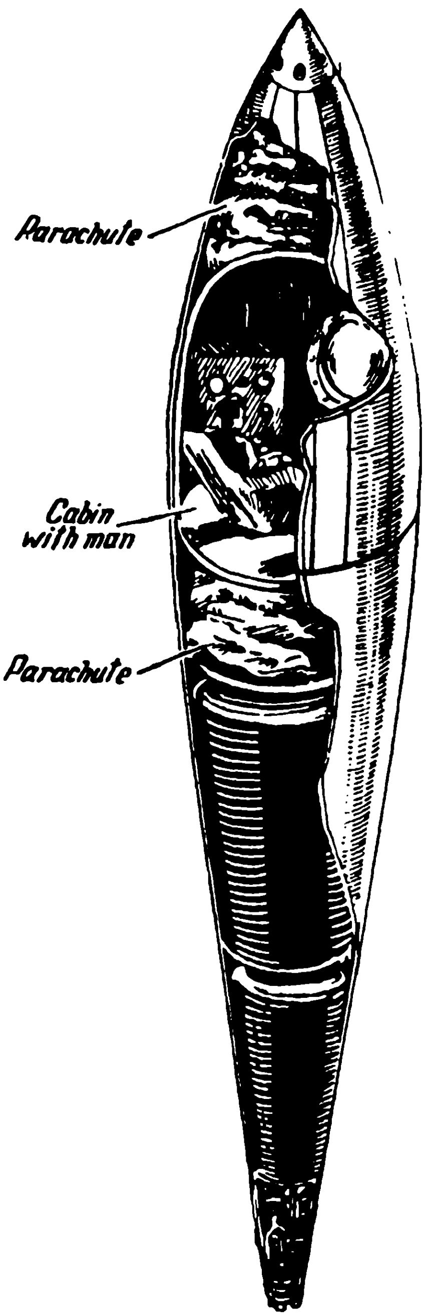
The situation is altogether different as regards the effect on a person during complete loss of weight, which occurs right after the overload vanishes after the take-off. As soon as the ship's engine is switched off and the ship begins its free flight, weight on the ship vanishes and the passengers become weightless. Of course, it is a pity to "lose" a quarter of a ton all at once, but that is quite unavoidable. The passengers of the ship will be "weightless" almost throughout the entire flight, which means several days during a flight to the Moon, or many months on longer flights. How will they feel under this condition? That is one of the most important questions of astronautics.

Usually the numerous fantastic romances and stories describe the absence of weight in passengers on a space ship as a sensation of extreme lightness, something extraordinarily pleasant and exciting. However, such will hardly be the case in actual fact. Very likely the first impression received when weight vanishes will be that of a momentary loss of support. It will seem as if one's support suddenly vanished from under one's feet, a feeling which will make one instinctively try to grab hold of something to keep from falling. Then one will experience a feeling of falling into a bottomless pit, a sensation not meant for weaklings. Throughout this period of weightlessness the passengers of the space ship will be in a state of constant tension, instead of experiencing a delightful sensation of lightness. However, we may hope that after long, persistent training man will finally be able to adapt himself to this condition.

* During the take-off of a space ship its control will probably be effected automatically so as to save the crew the need of exerting themselves physically. This is also desirable in order to increase the exactness of the take-off.



Allowable inertia overloads depend on position of man and duration of action of overload.



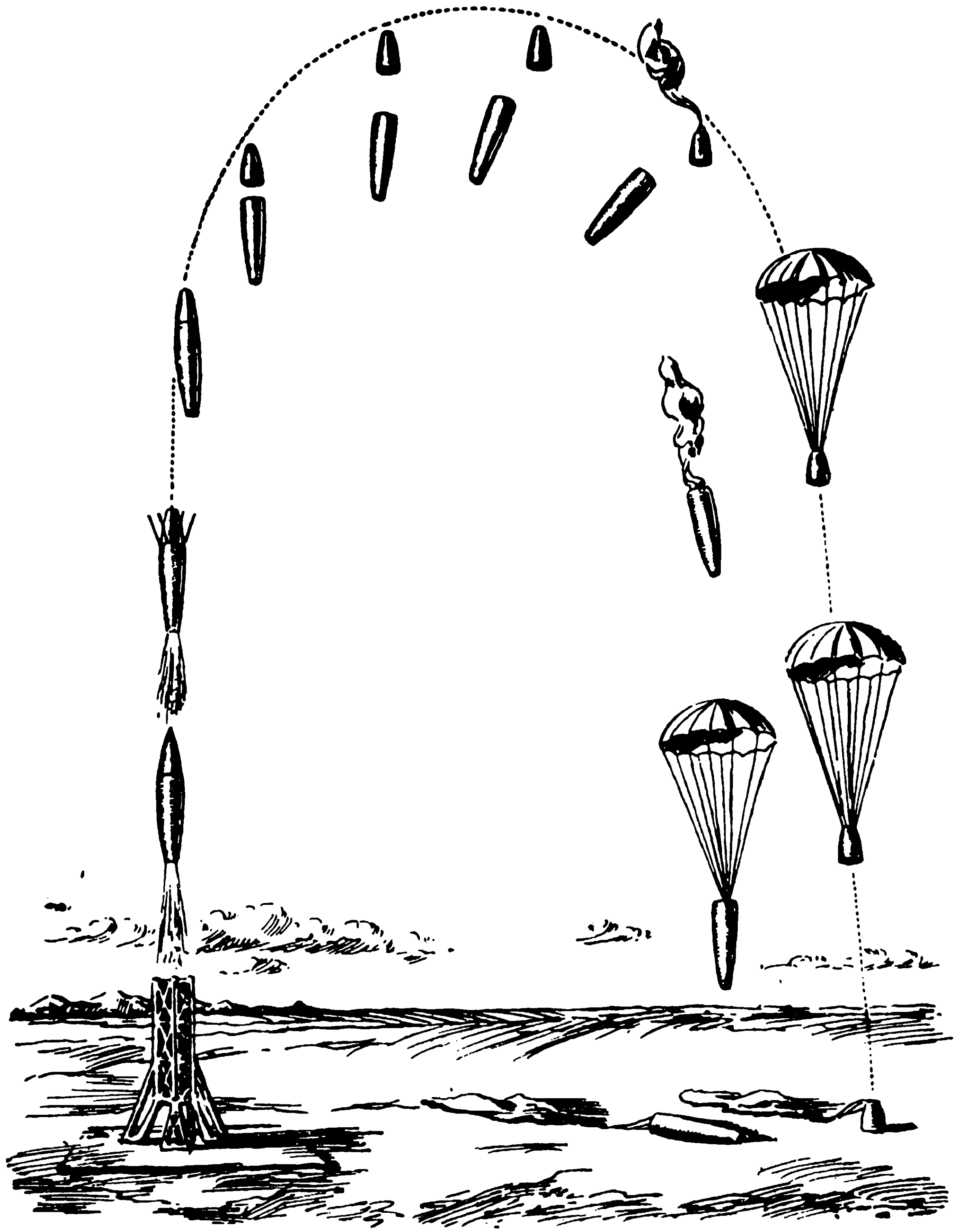
Project of rocket to study effect of weightlessness on man.

We do not know of a single vitally important function of the human organism whose fulfilment depends on weight. Respiration, circulation of the blood, digestion, motion—all of these functions are performed as a result of the action of the nervous system and the musculature of the human body, and do not depend on weight. Nor do the functions of the sense organs—sight, hearing, smell, taste, depend on weight.

Yet the absence of weight will, we may assume, cause a number of disorders in the human organism. The experience accumulated by science in this connection is still very little and we, therefore, unfortunately, have to confine ourselves merely to hypotheses based on our knowledge of the functions of various parts of the human organism.

The human organism has an intricate system of so-called mechanical receptors which give the brain, the central nervous system, detailed information about all forms of mechanical stimuli experienced by man. Among these mechanical receptors are the following: the vestibular apparatus of the internal ear, which reacts to a displacement of the human body; the sensory cells of the skin, which react to pressure; the muscle spindles which are contained in all those muscles which shift and fix the parts of the organism, and others.

The mechanical receptors play a significant part in the important psycho-physiological function of orientation. Under usual conditions a person determines his bearings in space because the mechanical receptors fix the direction of the force of gravity in relation to the person's position, and the sense of sight determines man's position in relation to the surrounding



Scheme of flight of rocket to study weightlessness.

*

objects. Both of these sensations are fully coordinated at such a time and merge into one sense of orientation.

But as soon as weight vanishes, the mechanical receptors fail to perform their function of orientation. If man is immobile, they may be absolutely "silent" and it will be necessary for him to find his bearings only with the aid of his sight. When a person moves, the mechanical receptors are excited, but only under the influence of the forces of inertia, which will impart weight that changes in value and direction, with the result that the signals of the receptors change. In this case the pictures registered by the mechanical receptors and by our eyes will differ.

The experience of pilots during blind flights in airplanes shows that man may suppress the incorrect information communicated by the mechanical receptors and be guided only by the recordings of his instruments. This very important trait is developed by pilots only through long training. However, certain investigations show that such a disharmony between the sensations and feelings, which are usually in complete harmony under normal conditions of weight, may evoke pronounced forms of seasickness. It is possible that the absence of weight may make the ocean of world space a very "stormy" one for astronauts, since they may be subjected to most vicious attacks of "space sickness."

For instance, it is possible that the absence of weight may cause serious disturbances in the action of the so-called vestibular apparatus of the internal ear, that organ of the senses which reacts to changes in position and direction of motion of the human body, and which plays a most important role in ensuring the equilibrium of the body at rest and in motion.

The problem of weightlessness is beginning to interest aviation as well. Modern high-altitude jet planes, when making a sharp descent from high altitudes where the air resistance is very little, can produce conditions of weightlessness for the pilots for 25-30 seconds. Such flights, however, have not evoked morbid sensations in most pilots any more than delayed parachute jumps from high altitudes.

In order to create conditions of weightlessness for a long period for purposes of investigation, certain special apparatuses are necessary. The first types were proposed by Tsiolkovsky. Today similar experiments are being conducted by using deep pits of coal mines, lifts, etc. During these experiments the person being studied is made firm in a special, freely falling cart, and during the fall his blood pressure is measured, his heart ac-

tion is studied, etc. It has been proposed that special high-altitude rockets be produced to study the effect of weightlessness on man. According to one such project, the rocket, which is built on the principle of the long-range rocket described in Chapter 6, should weigh 21 tons, 17 tons of which is the fuel. The passenger cabin containing a person will be located at the top of the rocket (the total pay-load will weigh about 1,300 kilogrammes). During the $2^1/_2$ minutes that the motor works, the rocket will fly off to an altitude of about 70 kilometres, and then, after making a free flight of about 230 kilometres, will, in a little over six minutes, reach a total altitude of 300 kilometres. After the motor is switched off a special mechanism detaches the cabin, which will make a free flight for five-six minutes and then come down by parachute.

The effect of weightlessness will be studied most fully when passenger rockets of over greater range and altitude will appear, and, later, orbital rockets, the artificial satellites of the Earth. At present we cannot say with certainty whether it will be necessary to create artificial weight on space ships or whether half-measures, such as magnetic soles fixed to one's shoes, will be sufficient. Most likely artificial weight will be created only on space ships making flights between the satellites of the planets, that is, for the main section of the cosmic trajectories.

Chapter 21

FATAL RAYS AND ERRANT MISSILES

Space in which the ship will have to fly is by no means "empty," even though it has no air. There really are few things in this space, yet it is very rich in energy, for it is permeated with powerful rays of all kinds.

How will this radiation affect the health of the astronauts? Will the walls of the space ship protect them against the effects of these rays should they prove harmful? A space flight can hardly be undertaken unless we know the exact answers to these questions, unless we are certain that the rays penetrating space will not be fatal or even simply harmful to the passengers of the space ship.

We who live here on Earth do not have an exact idea of what the rays penetrating space actually are. Because of the filtering properties of the terrestrial atmosphere, we here, on the surface of the Earth, can detect only

the weak reverberations of those powerful processes which take place in the upper atmosphere under the influence of the rays that force their way into it from space. Only an insignificant part of the original rays reach the Earth's surface. Nevertheless, science has been able to fathom this mystery of nature by means of most delicate instruments which have been sent up to great altitudes in sounding balloons and in high-altitude rockets. The result of these achievements on the part of science is that we now have quite a definite idea of the nature of the rays which penetrate space, although other forms of rays, as yet unknown to us, may, of course, be discovered in the future.

Certain rays have a harmful effect on the human organism, and if absorbed in large doses may even prove mortally dangerous. The question raised at the beginning of this chapter is, therefore, not an idle one. The passengers of a space ship must be protected against the harmful effects of various forms of cosmic radiation. Such a space flight as will end by delivering to its destination only the remains of the passengers, killed en route by fatal rays, can hardly be considered a successful flight.

Of all the rays that penetrate the space around the Sun, now known to science, those dangerous to man are the ultraviolet solar rays, the solar X-rays and the so-called gamma-rays. Other dangerous rays are the cosmic rays mentioned above. To be more exact, they are not really rays but streams of electrically charged particles emitted by sources whose nature has not as yet been exactly determined.

Electrically charged particles are also emitted by the Sun. It is these particles that produce the aurora borealis, or the northern lights.

Ultraviolet radiation, which is not weakened by the atmosphere, can burn the skin seriously.* However, the skin of the space ship and the glass of the illuminators of the passenger compartment will obviously fully protect the astronauts against the harmful effect of this radiation.

* The usual sunburn which, on the whole, is of value to man, is caused by rays lying in the so-called close ultraviolet region of the spectrum. Harder ultraviolet rays, those having a shorter wave-length, are already dangerous to one's health. These rays are retained by the ozone diffused in the atmosphere at altitudes up to 60 kilometres. Rays of an even more distant ultraviolet region of the spectrum, which are also harmful to one's health, are stopped by the oxygen, nitrogen and other gases of the terrestrial atmosphere. These rays kill the bacteria in the air. If they reached the terrestrial surface, life on Earth would probably be impossible.

X-rays and gamma-rays harm the body in much the same way as the hard ultraviolet rays do, the only difference being that these rays penetrate deep within the human body and affect the internal organs. They ionize the molecules of the substances which comprise the cells of the organism, thus converting them into electrically charged particles. The result is that the cells of the living tissue in the organism, subjected to such radiation, perish or their functions are interfered with. If the dose of rays that are absorbed is great, considerable harm may be caused to the organism: a malignant blood disease may set in because of the change in the number and composition of the white blood corpuscles, the function of the bone marrow may be interfered with, etc. However, we may assume that the intensity of the X-rays and gamma-rays released by the Sun is less than the amount dangerous to man, although science as yet does not have exhaustive data on this question. And when we take into consideration the protective effect of the skin of the space ship, we may assume that this radiation will not be of great danger to space travellers.

The situation as regards cosmic radiation is more complicated. The particles of which these "rays" consist whirl about at a tremendous speed and possess energy which is millions of times greater than the energy of all the other particles known to science. This is especially true of those heavy particles recently discovered, which are part of the so-called primary component of the cosmic rays along with the light particles that are basic for it, the protons, that is, the nuclei of hydrogen atoms. The heavy particles are the more complex nuclei, beginning with helium and ending with indium, and even heavier ones; their mass is from four to sixty times greater than the mass of the proton.

The action of cosmic rays on the human organism in many respects resembles that of radioactive radiation, but the cosmic particles cause much greater destruction in the human body.

Furthermore, the "bullet-like" action of the heavy primary particles on the tissues of the organism may prove serious because of the tremendous speed these particles possess. However, the relatively small density of cosmic radiation gives reason to hope that it will not present any serious danger.

At the present time there is no authoritative data on the effect of cosmic particles on the health of man, especially about the heavy particles which possess great energy. Yet these problems have already arisen in aviation

in connection with the question of increasing the ceiling of modern aircraft.

If the physiological effect of cosmic particles is to be investigated, high-altitude flights are necessary, and these are possible only by means of rockets. Experiments have already been conducted with various insects, as moths, which have been confined in high-altitude rockets. Parrots, mice and even monkeys have been flown to the ionosphere, but this is only a feeble beginning.

In the future, similar flights will have to be made with various animals and then, finally, with man.

A space ship flying through space at a great speed will encounter on its way not only rays and streams of invisible elementary particles of substances. Space will attack our ship, firing at it point-blank with artillery of all possible calibres. And every missile that hits the ship may prove fatal to it.

What are these missiles which threaten to destroy the space ship? They are meteoric bodies, celestial stones which plough the space around the Sun in all directions. These "errant missiles" are one of the great dangers during a space flight.

Some of these meteoric bodies are mere specks of dust; others are tremendous fragments of celestial bodies, entire mountains rushing about in space and usually surrounded by a suite of smaller bodies. There are isolated meteoric bodies which may be akin to the asteroids (discussed above), and there are whole streams, swarms of such bodies which go whirling in elliptical orbits around the Sun, obviously the remains of comets. The solar system is the birthplace of the absolute majority of such meteoric bodies, but some of them may have been born elsewhere, in other stellar worlds.

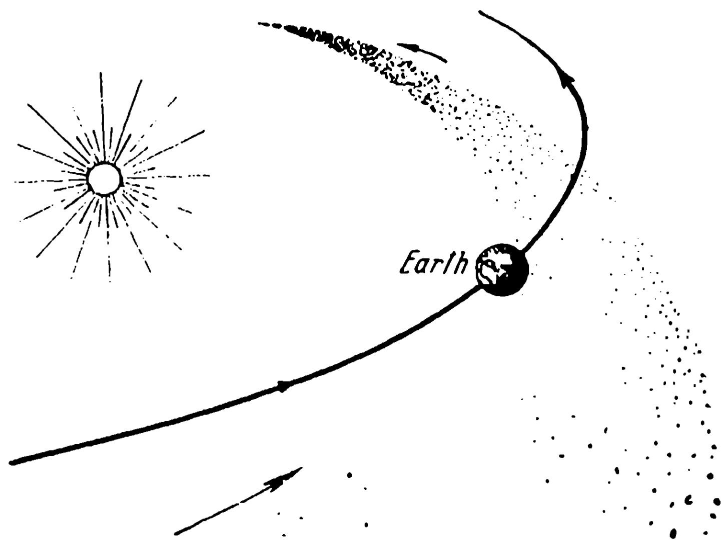
There are meteoric bodies which move at relatively small speeds in relation to the Earth, and there are such whose relative velocity reaches 200 kilometres per second. Most of the meteorites are of stone, consisting chiefly of silicates, that is, a combination of oxygen and silicon, while a fourth part is of iron. The rest, about $^1/_{10}$, are iron meteorites consisting of about 90 per cent iron and 9 per cent nickel.

A hypothesis suggested of late is that a considerable part of all meteoric bodies consists of ice, i. e., frozen gases of all kinds.

The world was once overwhelmed by the catastrophe that followed when the *Titanic* collided with an iceberg in a fog. But how insignificant

does such a collision seem in comparison with the possible encounter of a space ship and a mountain rushing at a terrific speed in the darkness of space. After such an encounter not even the slightest trace of the ship will remain, and it will simply be registered in the list of space ships reported as "missing."

We all understand, of course, why this problem of a collision between a space ship and meteoric bodies should hold the attention of astronautics, for it may prove fateful as regards even the very possibility of making a space flight. This problem consists essentially of two independent questions: first, it is important to know what is the probability of a collision between a space ship and meteoric bodies of all kinds, that is, of various dimensions, composition, and flight speed; secondly, we must know what may happen when such a collision between a ship and a meteoric body takes place.



Swarm of meteors.

How real is the danger of a collision between a space ship and a meteoric body?

Judging from the truly colossal number of meteoric bodies that are constantly making their way into the terrestrial atmosphere, producing the remarkable picture of "shooting stars," space abounds in meteoric bodies.

Indeed, as observations have shown, no less than several scores of millions of meteoric bodies of all kinds and, according to certain data, even thousands of millions of these cosmic missiles, having a total weight of 10-20 tons, make their way into the terrestrial atmosphere every day. The supposition is, therefore, often made that it is practically impossible to pierce such a "curtain of fire."

However, such a pessimistic conclusion is, to say the least, too hurried a one.

In the first place, there is a tremendous difference between the Earth, which has a diameter of about 13,000 kilometres and a powerful field of gravitation, and the space ship, which is only several scores of metres in length and has no field of gravitation of its own.

Furthermore, most of the meteoric bodies that break into the Earth's atmosphere are so insignificant in size that their collision with the space ship can be of no danger to it whatever, and it may, therefore, be ignored.

In order to attempt to determine the probability of a collision between a space ship and a meteoric body by theoretical calculation, we must know the density of these bodies in the space near the Sun, that is, their total number which passes through a given volume of space in a unit of time, and the direction of their flight. The only means of obtaining a reply to these questions today is through observations of meteoric bodies that fall on the Earth. Only rare and only the very largest meteoric bodies reach the Earth's surface. These include the famous Sikhote-Alin meteorite (1947) and the no less famous Tungus meteorite, which fell in 1908 near the river Podkamennaya Tunguska in Yakutia, and which set afire the imagination of writers, who lost no time in announcing that an atomic ship carrying Martian inhabitants or inhabitants from Venus had exploded.*

Such meteorites are so rare that there is no need to speak of them.

Most of the meteoric bodies do not reach the Earth's surface, but burn up in the atmosphere, leaving a bright luminous meteoric trail, which we see as a "shooting star."** This trail enables us approximately to establish the number of meteors that fall on Earth at night; we can thus determine the total number of meteors that fall during the course of one entire day, although very approximately.

Recently another very valuable method was introduced to register the fall of much smaller meteoric bodies, those not discernible in telescopes. Furthermore, it can be applied with equal success day and night. This method is based on the use of radar stations.

The kinetic energy of a meteoric body which breaks into the Earth's atmosphere at a tremendous velocity and burns up in it is converted into thermal energy which heats up the "air cushion" moving in front of the

* We can assume that both these gigantic meteorites were small asteroids which are of the same nature as meteorites.

** Usually the meteors flare up at altitudes of from 160 to 100 kilometres, and go out at altitudes of from 60 to 40 kilometres.

meteor. It is also converted into light energy, enabling one to see the meteor, and into energy which ionizes the air molecules located near the falling meteor.

These forms of energy are distributed approximately as follows: the thermal energy is 100 times greater than the light energy, and the latter is 100 times greater than the ionization energy, that is, only one per cent of all the kinetic energy is converted into light and 0.01 per cent into ionization energy. All the rest of the energy is transformed into heat.

Nevertheless, the column of ionized air formed in the atmosphere following the flight of a meteor through it is several kilometres in length and is an indisputable sign by which a radar station not only establishes the fact that a meteor has flown by, but even determines its approximate size. A radio beam sent into the heavens collides with this column of electrified air and is reflected by it as by an obstacle. The reflected beam is caught as a radio echo in the receiving part of the radar unit, permitting one to judge of the altitude of the meteor's flight and its size.

According to the data of observations that have been made, the total number of meteoric particles which threaten to collide with a space ship can be estimated from the fact that about 100 million such particles fall on the Earth in one day. This figure takes into account only particles not less than one milligramme in weight. Even such an insignificantly small particle, which is no larger than a speck of dust, if it has a velocity of tens of kilometres per second, is a mortal danger to man, for it will produce the same effect on him as a point-blank shot from a large calibre pistol.*

If we know the total density of the meteoric bodies and if we assume that one and the same quantity keeps whirling about in all directions, we can determine the time that will elapse between two successive collisions of the space ship and the meteoric body.

Such calculation shows that a collision between a space ship and a meteoric body which is capable of piercing its surface will take place not oftener than once in ten years. The likelihood of a person being struck by lightning here on Earth is much greater.

* A typical case showing how dangerous is a collision at a great speed occurred recently with a jet bomber. It collided with a sea-gull during flight. As a result of this collision a hole was formed in the wing of the bomber, 150×200 mm. Just imagine a bird piercing that thick sheet of metal!

There is no doubt whatever that on every flight the ship will encounter, and frequently at that, microscopic meteoric bodies having a diameter of less than 0.01 millimetres but such collisions will merely scratch the surface of the ship, dulling its original gloss.

It should be pointed out that should the ship fly into a meteoric swarm, the likelihood of a collision will be greatly increased, and instead of one dangerous collision in ten years, such collisions may occur once in several months.

That is why these meteoric showers will have to be avoided even though they are not very dangerous for ships making a trip to the Moon, which will take no more than 100 hours.

Another important question connected with the problem of a collision between a space ship and a meteoric body is: to what extent will such a collision hurt the ship? For no matter how rare such possible collisions between the ship and sufficiently large meteoric bodies may be, as we have seen above from calculations based on the theory of probability, they are, nevertheless, possible.

The crew of a ship which has collided with a meteoric body will find little consolation in realizing, just before they perish, that theirs was one of the exceptional cases.

Even the possibility of a rare collision should be prevented so that space travel will be safe in the maximum degree in this respect as well.

Unfortunately, at the present time science does not have any data on the destruction caused by missiles flying at speeds of 100 and more kilometres per second. Artillery deals with missiles whose velocity usually does not exceed 1.5 kilometres per second.

We can only assume that the basic destruction caused by a collision between the ship and a meteoric body will result from the explosive evaporation of the meteoric body itself and a certain part of the ship's skin. Even at a speed of four-five kilometres per second a solid body begins to look like an intensely compressed gas and it explodes on colliding. This probably explains why, at the site where the Tungus meteorite fell, not even the slightest piece of the meteor could be discovered. It had all evaporated.

Certain calculations show that the depth to which a meteoric body will penetrate the skin of a space ship will be approximately proportional to the diameter of that body. In the lightest case, when the ship's skin

is made of steel and the meteor is of stone, it will pierce the skin to a depth of three times its diameter. In the most serious case, when the skin is made of duraluminium and the meteor is of iron, the latter may penetrate the skin to a depth of about 16 diameters. Thus if we know the material of which the skin is made, we can calculate its thickness, also the probability of a collision between the ship and the meteoric body and how often one can expect the skin to be pierced during such a collision.

Judging from approximate calculations one can expect the steel skin of the ship, which is one millimetre thick, to be pierced about once in several months of flight. Needless to say, not every such collision will end in a catastrophe, for the hole can be patched up. Furthermore, the walls of the passenger compartment can also be protected, as is done with fuel tanks on airplanes and, of late, with airplane and automobile tires. In this case a layer of a special substance spread on the inner surface of the wall will patch up the hole.

The danger of a hole in the skin of the ship will be greatly diminished if it is equipped with a special anti-meteoric protective screen. Such a protective screen made of sheet duraluminium one millimetre thick, in the form of a skin for the ship, leaving a space of 20-30 millimetres between it and the surface of the ship, will decrease the probability of a hole being pierced in the ship's skin from once in several months to once in decades, as the greater part of all the meteoric bodies will evaporate when they collide with this screen.

Thus the danger of a collision with a meteoric body should not prove an obstacle in the way of space travel. Yet the space ship should be completely free of the danger of even an accidental collision which may threaten destruction. Such a degree of safety may be achieved by means of a radar unit on the ship. A radio beam sent by such a unit will constantly "feel" all the space around the ship over a stretch of hundreds of thousands of kilometres. If the ray discovers a meteor* a warning signal will light up on the screen near the commander of the ship. An apparatus which determines the velocity and direction of flight of the ship's

* At the present level of development of radar technique only a very large meteor, a whole interplanetary mountain, can be located in this way. The usual, even rather large meteors, will be discovered by radar only at a distance of several kilometres, which will be of no value whatever.

dangerous neighbour in space is switched on either by the commander or automatically. It makes the necessary calculations, and if there is danger of a collision it shows what change should be made in the course of the ship. The ship's motor will be switched on instantly, and this will be sufficient to obviate a tragic collision. Perhaps instead of switching on the ship's motor it may be possible to use a "gun" of rays, which will send a powerful pencil of electrically charged molecules, ions of some substance, from the ship to combat the meteor, or short-wave radio beams. The force of reaction of these rays will deflect the ship somewhat and also the meteor, as a result of which their trajectories, which had intersected before this, will now diverge. If successful, the passengers of the space ship will get a fleeting glance of the meteor which, illuminated by the ship's powerful searchlight, will glide past the illuminators of the passenger cabin at a tremendous speed, as if silently reminding them of the terrible danger they have just escaped.

Part Six

A LOOK INTO THE FUTURE

It is absurd to deny the role of fantasy even in the most exact of sciences.

V. I. LENIN

Chapter 22

FROM MOSCOW TO THE MOON

It was a warm summer evening, the first evening in July 19....

There was a great deal of excitement in the Little Hall of the new Moscow Planetarium, which occupied several upper floors of the new skyscraper, the House of Astronomy. Youths and girls in their teens, who filled the hall, collected near the colourful diagrams and pictures that were hung on the walls, crowded about the scientists who were still present in the hall, and gathered together in small excited groups. All were full of the impressions left by the meeting they had just attended, and were loath to leave for home.

At the meeting a circle of young astronomers, which was organized at the planetarium, had reported on their activities for the past school year. Members of the circle, students of the upper grades of Moscow schools, had assembled in this fashion not for the first time, to review the year just ended, a year full of interesting, absorbing activities, and also to take leave of their older comrades, the seniors, who would now be leaving their school circle.

However, this evening was different from the usual ones. This year marked the 15th anniversary of the first manned flight to the Moon, and the public, far and wide, was celebrating the achievements of astronautics in the fight to conquer space. As the years went by there was hardly a

place in the solar system which had not been frequented by the Earth's emissaries. At the meeting just ended the director of the planetarium had read a decision of the Academy of Sciences to the effect that in honour of the anniversary of the first flight to the Moon ten members of the Young Astronomers' Circle, who were also honour pupils at school, would, beginning with this year, be annually awarded excursions to the Moon. It was this announcement that had aroused such excitement among those present. Each one congratulated the fortunate students, and at the same time wondered if he would be able to win the right to take part in such an excursion the following year.

But most excited, of course, were those whose names were in the list of the selected ten. What interesting things they would see! How many things they would learn! The young astronomers were already completely absorbed in the coming flight. If only that wonderful day, when they were to fly off, were already here! But they still had a whole week to wait.

However, this week would be full of most interesting events also. Many instruments and apparatuses would have to be prepared, as the excursionists planned to make numerous observations during the flight and while on the Moon itself, about which they would later report to their circle. Once again they had to reread books about the Moon and books describing space ships and flights in them. It would not do to show the crew of the ship they were to fly on that they were novices and ignoramuses, besides which, they themselves wanted to know all about everything. And how many other things had to be done before that long-awaited day would come, the day they would take off....

The day after the next they were to meet at the planetarium, from where they would go on an excursion to the Moscow cosmoport.

Two days later the group of young astronomers flew off to the cosmoport on a large helicopter. The cosmoport, which was 30 kilometres from Moscow, had a landing place for the helicopter on the flat roof of its main building. The engineer there met the excursionists as they climbed out of the helicopter. Then they all went over to the lacework parapet at the edge of the roof. Before them they saw a panorama of the cosmoport. The engineer told the young people of its work. It was one of the largest cosmoports, and dozens of ships had already flown off from it on their way into space.

Various buildings and structures were scattered over its vast territory, and were connected with each other by concrete paths. Beautiful green lawns, flower beds and fountains could be seen here and there among the buildings. The whole rear part of the field was occupied by an aerodrome belonging to the cosmoport. Jet planes of various types kept landing and flying off all the time. The people they transported came from various cities throughout the country. Some were about to set off on a space flight; others were going to make high-altitude flights for research purposes; still others attended to the diverse needs of the cosmoport. To the left were the long light buildings of the repair works, which was not only able to repair and re-equip such space ships as already existed, but was also able to build new ones, in accordance with the projects of the designing bureau of the Interplanetary Building Trust. The latter was located in the five-storey building that stood a bit to one side, right near the grove that bordered on the territory of the cosmoport.

To the right, hidden among the greenery of the gardens, were the sparkling, white cottages of the employees of the cosmoport. And a little farther off was the observatory where scientists, day and night, studied the solar "household," which had been entrusted to them. Right near the observatory they saw the typical outlines of powerful radar units of a radio station, which maintained constant radio connections with the communities on the Moon and the planets, with the crews of space ships and with the members of interplanetary stations.

But what attracted greatest attention were the tremendous towers, as high as skyscrapers. As the excursionists caught glimpses of them through the lacework of the parapet, they recognized the attractive outlines of the space ships. These towers were set up on concrete squares in front of the main building, at a distance of a few scores of metres from each other.

In the background, nearer the aerodrome, in a rather distant corner, were two or three other towers of smaller dimension but similar to the big ones. The guide explained that these smaller towers were used for research purposes and the testing of space ships, whereas in the main towers ships were made ready for space flights. The engineer also explained that beneath the cosmoport, at a depth of scores of metres, were gigantic subterranean cisterns containing fuel for the jet engines of the ships.

One of the pupils could not refrain from asking to be allowed to have

a closer look at the space ships. The others immediately joined in, repeating his request.

"I understand your impatience," said the engineer, smiling. "We will go and see them now. But let's agree upon one thing: you won't touch anything yourselves, or we will all be asked to leave immediately."

A lift quickly delivered the entire group to the vestibule of the main building, where a colourful mosaic map fixed to a marble board showed what places the space ships which had taken off from the Moscow cosmoport, had already reached. Numerous lines, all of which radiated from a red star bearing the inscription "Moscow," silently told of the achievements of Soviet astronauts during the years that had elapsed since the first flight had been undertaken.

But let's hurry on to the ships!

Is there any need to say that the excursionists enthusiastically accepted the invitation of the engineer to take them around and show them the very ship on which they were to make their distant flight to the Moon five days later? The ship had been set up in one of the towers and was being fitted out for its trip. Lifts kept scurrying up and down the shafts of the tower, raising and lowering freight of all kinds. People kept bringing instruments and equipment. At various levels from the bottom of the ship to its very summit, which extended high into the sky, workers stood about on platform-lifts, separately or in groups of twos and threes, as they worked on the surface of the ship. You could hear the drone of electric drills, see the flashes of lightning emitted during welding, while pneumatic hammers rat-tatted like machine guns.

The ship was standing vertically inside the tower, resting on its concrete foundation. It was really a beautiful thing, one of the ships on the through express line Moscow-Moon. This ship, considerably larger than those in the neighbouring towers, which flew only to interplanetary stations, immediately won the hearts of its future passengers.

The first experimental ships with atomic jet engines had already traversed the Moscow-Moon route, but they had not as yet made any regular trips with passengers. The ship on which the young astronomers were to fly had jet engines which used the usual chemical fuels.

The excursionists stopped at a little distance from the tower where "their" ship was standing. The very first figure named by the engineer filled his audience with awe, and they glanced at each other in amazement

and rapture. This ship would weigh 940 tons at take-off! That was much more than the very heaviest airplanes weighed and corresponded to about the weight of four powerful railway locomotives. The engineer went on to explain that the first ships that went to the Moon had been even heavier, for they had had to ensure the return of their passengers to the Earth and could not hope to be refuelled anywhere en route. Ships that were now refuelled at interplanetary stations, in particular those that were standing near by, were about half as heavy.

"By the way," the engineer added, "you can judge for yourselves how difficult it was for our fathers to make a flight to the Moon. In their days, that is, at the beginning of the second half of our century, the fuels used in jet technique were only half as good as those now used. That meant that a ship like this one had to weigh hundreds of thousands of tons at take-off, and not a mere 940 tons. That also explains why their dream of making a space flight could not be realized for such a long time. The height of this ship is over 50 metres; its diameter at the widest part is six metres. As you see, its shape reminds you of a gigantic cigar, equipped with triangular wings in front. At take-off 814 tons of the total weight of 940 tons is the weight of the fuel. That is over 86 per cent. And less than 14 per cent, only 126 tons, is the weight of the ship itself, its equipment and its passengers. But does this mean that when the ship lands on the Moon with empty fuel tanks it will weigh 126 tons?"

The engineer looked expectantly at his youthful audience.

Several of the youngsters called out, one after another:

"No; it's a multi-step ship!"

"Well, well, I see you are real astronauts, there's no denying that. Yes, indeed, the ship on which you will fly is a multi-step ship. That is why you won't recognize it when you climb out of it at the Moon. It will look much less impressive. Only the front part of the ship will reach the Moon. With you on it, of course, so don't get so upset! This is a three-step ship. The lower step, which is the very largest part of the ship, is the first step. It weighs 100 tons and will carry 685 tons of fuel, so that its total weight will be 785 tons. The next step, the second, is only $^1/_5$ as heavy; it weighs 20 tons and together with its 113 tons of fuel will weigh 133 tons. Then we come to the last step, the third, which is the winged step, and in which the passenger compartment is located. That weighs only four tons, and together with the passengers, necessary equipment, foods

supplies, etc., that is, with its pay-load, it weighs six tons. This step will contain 16 tons of fuel, so that the total weight will be 22 tons. When the ship lands on the Moon it will weigh less than six tons* if all the fuel has been consumed, or somewhat more if, as we may assume, there is still some fuel in the ship's tanks. That is the answer to my question. And so you see, from the moment of take-off to the moment of landing, the weight of the ship will decrease from 940 to 6 tons; it will 'lose weight' until it is only $^1/_{157}$ of its former weight. It is not surprising that Tsiolkovsky had to write a new chapter on mechanics, the theory of the motion of bodies with a variable mass. Without that we would be unable to calculate the flight of a space ship.

"The required fuel supply on the ship is determined by strict calculation and, of course, according to Tsiolkovsky's formula. You can calculate it yourself before you fly off so that you will be certain the ship has enough fuel to last for the entire, long trip. When making your calculations you must bear in mind that a new type of fuel has been poured into the ship's tanks, one capable of producing a great amount of heat. Liquid ozone serves as the oxidizer, while the combustible is one of the hydroborons, that is, a combination of boron and hydrogen. The jet velocity of the gaseous products formed by the combustion of this fuel will be over four kilometres per second. The fuel supply for the ship was calculated on the basis that the energy given off by this fuel during combustion will impart to the ship a velocity of 15.6 kilometres per second if there is no force of gravity or air resistance."

"And what thrust will the ship's engines develop?" one of the youngsters asked.

"Well, well! We can talk about the engines if you wish to," their guide said. "The thrust of a ship's engine cannot be whatever you wish it to be; it depends chiefly on the acceleration at the take-off of the ship and, of course, the ship's weight. The greater the acceleration at take-off, the greater must the engine's thrust be. A take-off with a great acceleration is advantageous from the point of view of fuel consumption, but the first consideration here must be the health of the passengers. You're really in luck: this ship is calculated for overloads not exceeding three,

* To be more exact, that is what its weight would be on Earth. On the Moon it will weigh $^1/_6$ as much.

whereas other ships still fly with overloads equal to four, and their passengers feel worse.

"But if the inertia overloads are equal to three, that means that the acceleration of the ship during flight, created by the motor, will be three times the acceleration of the Earth's gravitation, which, as you know, is equal to about 10 metres per second for every second. In other words, the thrust of the motor will increase the ship's velocity every second by 30 metres per second. And so each of you, while on the ship and so long as the engine operates, will weigh three times as much as you now do. I suggest that you weigh yourselves before you fly off so that you will know your record weight on the ship. But this also means that the total weight of the ship at such a take-off run will increase threefold, so that during the take-off it will weigh 2,820 tons and not 940. And that's the value of the thrust which the engines of the first step of the ship would have to develop at take-off if they did not have to overcome the resistance of the air.

"The first step of the ship has seven liquid-fuel rocket motors, each of which can develop a maximum thrust of 450 tons. That is tremendous, and is equivalent to the thrust of 20 powerful diesel engines. When all these engines operate at the take-off of the ship, developing their maximum thrust, they consume over $7^1/_2$ tons of fuel every second, or over a ton per engine. The turbines which set in motion the pumps that deliver the fuel to the combustion chambers of the engines develop over 25,000 h.p. That is the same as the power of the electric stations of large cities.

"As the fuel is consumed, the total weight of the ship is decreased. The thrust of the engines must decrease likewise in order to keep the overload constant all the time, equal to three. There is a special automatic unit to decrease the thrust of the engines; it is connected with an instrument that measures the acceleration, the accelerometer, and it decreases the delivery of fuel. This causes the pressure in the combustion chambers of the engines to drop and the thrust decreases. By the time the motors of the first stage finish working, that is, when they have consumed all of their 685 tons, the weight of the entire ship will have been reduced to 255 tons, and the thrust of the engines—to about 800 tons.

"When this happens, the first step is automatically separated and descends to the Earth by means of a large, special parachute. This step can still be used on many a ship. The motors of the second step are switched

on automatically. The interval in the work of the motors should be a minimum as it causes a loss in velocity. This interval should not exceed several tenths of a second. But there won't be any such interval on your ship; the designers have thought of something very clever to avoid it. I'll tell you about it if you aren't tired."

"Please do!" came the unanimous request from all sides.

"Well then, just listen. The walls of the ship which you see aren't its walls at all. Annular fuel tanks have been installed on the outside of the ship. It is their surface that you see. There, just take a look in that direction; that tank hasn't been installed yet and you can see the real wall of the ship there. When all the fuel in these tanks has been consumed, and this fuel will be the first to be used up, the tanks will be detached and jettisoned. This idea of jettisoning the empty tanks has been borrowed from aviation. It is used by airplanes, in particular, by jet planes. And so, when the tanks of the first step are being thrown overboard, they disclose the outlet nozzles of the engines of the second step, which are located on special brackets on the circumference. This makes it possible to switch on the engines of the second step even before the first step has been detached, so that there is no interval in the work of the motors. Is that clear?"

"That's great!" the youngsters exclaimed, simply delighted. "And the same thing happens with the second step, doesn't it?"

"No, the second step, it is true, also has tanks that can be jettisoned, but the motor of the last step, the third, is located in the centre along the axis of the ship, and not in back but in front.

"It has been designed in this way because the motor is switched on only to brake when landing on the Moon.

"Since the total weight of the ship after the first step is separated from the vessel, is only 155 tons, the maximum thrust of the engines of the second step will be almost 500 tons, as it must again be three times the weight of the ship. Then the thrust gradually diminishes to 130 tons, when all of the 113 tons of fuel that have been stored up on this step have been consumed. The second stage also has seven engines each of which has a maximum thrust of 70 tons. One such engine is installed in the last, the third step of the ship, which will reach the Moon together with you. The minimum thrust of this engine when it lands will be equal only to several tons."

"How much time do the engines of the ship actually work, taken all together?"

"A little over eight minutes; of these eight minutes about six are spent at take-off. The rest of the time—and your flight to the Moon will last slightly over three days—the motors are switched off. What forces affect the ship during this period? Only the forces of gravity. The ship will be attracted by the Earth, the Moon and the Sun. At first the attraction towards the Earth will be felt most strongly, so that the ship will fall freely on it, the way an apple falls from a tree. But whereas the apple actually falls to the Earth, your ship will not, of course, for it will be whirling away from the Earth at a tremendous speed. The Earth's attraction will affect only the ship's velocity, which will keep dropping all the time. When the ship approaches so close to the Moon that the attraction towards the Moon becomes greater than the terrestrial attraction, it will no longer fall towards the Earth but towards the Moon, and its velocity will again begin to increase. And so, as you see, you will be falling freely all the time, first to the Earth and then to the Moon."

"That means we won't weigh anything at all?" the young people asked, all at the same time.

"Exactly! Your weight will vanish completely. And to prepare for that feeling of weightlessness and avoid all sorts of mistakes during the first moments of such a free flight, you, like all other space travellers, will have to train on a special apparatus we have here at the cosmoport. You will have to come here once or twice especially for this purpose. Any objections?"

The question was obviously superfluous.

The secondary school pupils followed the engineer all over the territory of the cosmoport for a long time, climbing up to the tops of towers, looking into the inner part of the ships, and inspecting the observatory. They even visited the plant and the designing bureau of the Interplanetary Building Trust.

It was already dark when these youthful excursionists, tired but happy and proud of what they had learned, got into their helicopter. Powerful searchlights illuminated the entire territory of the cosmoport and the landing places of the aerodrome. Red stars, warning lights, glittered on the tops of the towers. When the helicopter whirled up into the air almost without a sound, the youngsters saw a sea of lights ahead of them, the

lights of their beautiful native city, Moscow. They could hardly wait to get home and begin training the very next day for their flight, as very little time remained before they would take off.

The remaining days flashed by in the fuss and bother of countless things that had to be done, and at last *the* day arrived.

The ship's take-off was set for 3 p.m. But the young astronomers were there long before the appointed time. They were surrounded by their relatives, school-mates and comrades who worked with them at the planetarium. After they had listened patiently (for the nth time) to all sorts of admonitions, requests and good wishes, the young travellers were asked to take their places in the ship.

Here is the space ship. The tower was now fixed to the ship only on one side. The other half of the tower (we discovered that the tower consisted of two halves) had been taken aside via a special track. A lift quickly delivered the passengers to the landing which was situated very high and from which they went up a gangway and passed through the door of the passenger compartment of the ship. The members of the crew, the captain of the ship, the second pilot, the pilot-radio officer and the stewardess, all of whom had already met the young passengers, were now in their places. The door of the ship was closed tightly and hermetically sealed. The tower was taken aside and the ship now stood proudly all by itself.

A green rocket was sent up into the sky and the air was instantly filled with the powerful roar of the ship's motors. For a second they operated on reduced thrust, the last check-up, and then the roar became intolerable. Fiery torches came sputtering out of the nozzles of the engines. The ship trembled, then slowly, as if unwillingly, tore away from its supports and went rushing upwards, ever quicker and quicker, leaving a long smoke-like trail behind it. For several moments one could see a silvery line in the sky, and then it vanished. Bon voyage!

Let us now return to the ship's compartment and see how our astronauts are getting along.

When the door of the ship slammed shut, the children discovered that they were locked up in the cabin. They would have to spend three whole days here during the flight to the Moon, and as many days on the return trip. Each took his place. They were "sleeping" places. All told, there were 10 berths in the passenger cabin, as many as the number of excursionists. These places were near the windows, alongside the walls of the cabin,

that extended upwards, and they reminded one of sailors' bunks, which are suspended one over another, but this time five bunks were placed one above the other, a sort of five-storey bedroom. There were rope ladders by which the passengers climbed up to their bunks and lay down on them. Some were even inclined to joke about it ("All hands on deck!" "Going to sleep already?"), but the solemnity of the moment embarrassed them. All realized that during take-off one simply had to lie on one's back in order to lessen the strain of the inertia overloads.

· Incidentally, the berths were excellent, with springs, and were very comfortable to lie on. All the youngsters lay on their backs, head towards the wall, where there was a vertical row of electric lights. Their feet were turned towards the other wall, which was covered by a thick rug with a black vertical strip down its centre. There was a door in the ceiling, which, as they later learned, led to the crew's cabin.

Silence reigned. No one felt like speaking. All seemed to be listening for something, very much excited, as if expecting something. Then it came! It was the roar of the engines, muffled, however, by the walls of the compartment. Another instant and some powerful force pressed the youngsters to their berths. Now, do what they would, they couldn't get up. They even found it difficult to breathe. The passengers then realized that the ship was already flying.

The children began to watch the clock with a huge second hand on the ceiling, above the door leading to the crew's cabin. Three minutes had elapsed. That meant that the first step of the ship, with its emptied tanks and motors, was already flying back to the Earth, descending by parachute. They had not even felt the first step being separated, or when the motors of the second step had been switched on.

The arrow of an instrument hanging on the ceiling beside the clock kept constantly moving around in a circle. It indicated the altitude above the Earth. They had already flown 200 kilometres. Instead of the customary light blue sky, the firmament as they saw it from their cabin windows was a dark dark-violet, almost blue-black, and it was filled with an unusual dull luminosity and thousands of stars. And in this most unusual sky the passengers saw a most unusual Earth. They even failed to recognize it at first, it was so unlike their native Earth, which they knew so well. The picture of the Earth as it unfolded before them now was quite unlike the Earth as they had seen it from the helicopter.

"What places are we passing?" they wondered. "We can't even recognize them. In any case, this must be somewhere in the east, for the ship is flying towards the east in order to take advantage of the Earth's velocity in its rotation about its axis."

The sky kept getting darker and darker, and more and more stars appeared in it. Yet at the very same time blinding streams of sunlight kept shining in through the opposite windows. Day and night ruled simultaneously in the ship's cabin.

Five minutes had elapsed, $5^1/_2$ minutes. Soon the motors would stop and the ship would part with its second step, the middle one. Now that heavy feeling, which had pressed down upon them, vanished.

Even though they had all been waiting for this moment, it came unexpectedly. The roar of the motors died down and the berths seemed to drop from under them. They, too, felt they were falling, falling into a deep, bottomless abyss. They convulsively grabbed hold of the edge of their berths and waited tensely, positive that they were about to collide with something and then—the end of everything....

Only after a little while did the youngsters recall that they had felt that very same way when training at the cosmoport. They all jumped up from their berths, but ... they remained suspended in the air in the most amusing positions. However, the strange state of things that followed soon began to annoy them. After all, it wasn't such a jolly thing to flounder around in the air, bump your head against the most unsuitable places, and not to know what was up and what was down ("We're falling, but upwards!"). It all caused such an unusual sensation! They even felt somewhat nauseous, as though seasick.

The stewardess, who appeared in the doorway on the ceiling—it was now hard to call that the ceiling, for things were so mixed up—put things in order to some extent. First of all she explained what was now to be considered the floor of the cabin and what was the ceiling, what was up and what was down. With the help of the youngsters she quickly transformed the berths into comfortable armchairs, which were placed beside the windows, one behind another, as in a bus, with an aisle between them. Now the wall with the row of lights became the ceiling and the other wall, with the strip down the middle—the floor. Incidentally, the mystery of that strip was now solved. In order to keep the passengers from flying upwards because of some careless movement, they were all given special

magnetic soles to attach to their shoes. These soles stuck to the iron strip and it now required some effort to get one's foot off the floor. How good they felt to have a floor beneath them again and not to have to hold on to it with their hands, in order to walk across it.

The door to the crew's cabin in the front part of the ship was now in front of them. As before, the hands on the round dial of the clock above the door kept turning around and the altimeter kept recording the kilometres they had covered in their flight from the Earth. They had already reached an altitude of 3,000 kilometres and the ship was whirling along at a speed of about 35,000 kilometres an hour. From the window they could see the Earth, their dear, distant Earth, where they had left their relatives and friends and Moscow. The Earth looked inimitably beautiful, covered with a haze of clouds between which one could discern the outlines of the familiar continents, whose edges were jagged by the mists.

A small dark disc began to climb up from behind the edge of the Earth. Indeed, that's the Moon! As yet it seemed far away and inaccessible. But just wait a bit! Before much time elapses they will see it at much closer hand.

Little by little they became accustomed to the unusual and, to tell the truth, the unpleasant feeling of weightlessness. Their training had stood them in good stead here. The stewardess came to the help of some of the youngsters, those who felt worse than the others. She gave them some pleasant aromatic tablets, after which they felt better, at least for a while.

Life under conditions of weightlessness is, after all, interesting. Nothing falls, nothing breaks, and you can sleep even on needles.

The air in the ship's cabin was fresh and clean, and the compartment was warm and cozy. A slight breeze came in through the ventilation jalousies. It was difficult to imagine that outside the thin walls of the ship eternal cold and the silence of airless space held sway.

Dinner time came. The service was most unusual. Each passenger received his portion in special interplanetary dishes. They had to be especially careful with the different liquids: the latter coagulated into balls of various sizes and rolled all over the compartment. An encounter with a ball of hot cocoa promised nothing good. All of these balls behaved most capriciously. They were difficult to swallow, and yet they rolled easily over one's face, covering it with a thin layer of liquid. But soon the

travellers learned to handle the situation and, as may be supposed, ate everything with a hearty appetite. They sucked the soup and cocoa up from the dishes through straws similar to those children use to blow soap-bubbles.

After dinner the pilot-radio officer came in to see how the young passengers were getting along. He proved to be a merry, conversational person who, in spite of his youth, had already acquired quite a bit of experience in space travel. His flying record in space now consisted of several hundreds of millions of kilometres, and he dreamed of becoming a "billionaire" in the future. Terrestrial pilots had long ceased to envy their interplanetary colleagues in this respect, considering it quite hopeless to try to catch up with them.

After introducing himself to his young companions, the radio officer told them of the latest radiograms received from the Earth. The passengers showered the officer with dozens of questions, and he had a hard time trying to answer them all. As far as possible he answered by giving practical illustrations. For instance, when he was asked if a match would burn in the compartment, he immediately lit one, and all were convinced that it would burn excellently. When one of the youths started to say. "But we heard..." the officer winked understandingly and said: "Just a minute." He left the room for an instant and when he returned he lit another match. It flared up, then the flame quickly curled up into a little ball and went out. The officer left the room again, and this time when he returned the match again burned quite normally. What was the answer to this riddle?

"You shut off the ventilation!" someone exclaimed.

"Right!" the officer returned. "Under conditions of weightlessness, if there is no special artificial ventilation the flame 'chokes.' By the way, you would be suffocated, too, if I turned off the ventilation system for any length of time," he added.

The second day of the flight was marked by their meeting an interplanetary station, an entire community of buildings of all shapes whirling in their orbit around the Earth at an altitude of over 100,000 kilometres without disturbing their order, like a hatch of strange birds. Pressed close to the windows of their cabin, the children looked on in silence as the "islands on the terrestrial shores," created by the will and genius of man, silvery in the rays of the Sun which illuminated

a wonderful "mooning" (compare "landing"). The whole operation took about $1^1/_2$ minutes. All told only a bit over three days had elapsed from the moment they had taken off from the Earth.

The dream of the children had come true! They were on the Moon! How interesting it was to look through the window at the landing place where people in space suits were walking about, and to see those strange-looking structures in the distance, the masts of radio stations.

In spite of the fact that it was night, it was light on the Moon. The Earth, a whitish-bluish disc (four times larger than the lunar disc), which was suspended in the sky, brightly lit up the surface of the Moon. The Earth's light is about 80 times brighter than the lunar light is for us on Earth. One can easily read a book on the Moon by the light of the Earth.

Before much time elapsed our young travellers climbed out of the ship, one after another, and in their space suits set off for the dwellings of the "selenites"—the Moon dwellers. Their living quarters, which were situated near this landing place (there were other communities as well), were under the surface of the soil, and only their round cupolas revealed the whereabouts of some of them. All the travellers entered one such sublunar hotel, which had been organized for the new arrivals, through the "lock," with which they were already familiar. After exchanging greetings the travellers were fed and put to bed, for they were going to get up as early as possible as they had an interesting day ahead of them.

Chapter 23

ON THE MOON

The young travellers were awakened early in the morning A lunar night lasts two weeks, as you know, and the lunar day is equally long, but on this particular day the lunar morning coincided with the terrestrial. It was early in the morning on the Moon as well, for the Sun was just about to rise. No one had seen it here for a fortnight. That was the surprise awaiting our young astronomers and about which they had been given a hint when they were still on Earth. But no matter how hard they had tried, on the way over, to guess what it was all about, they had been unable to. Their arrival on the Moon had been so calculated in advance, as to enable them to see the sunrise on the Moon. It was an unusually beauti-

ful and, as we see, a rather rare phenomenon. But then, the sunrise on the Moon lasts a whole hour, and not just a minute or two as it does on Earth.

No more than half an hour had elapsed when the children were already off with a guide, who had been assigned to them for their sojourn on the Moon. Clad in space suits, they marched off, one behind the other, to the place from which they were to observe the sunrise. As yet there was no sign whatever indicating that our daytime star was soon to appear. The sky was not coloured as it is on Earth just before the Sun rises, for the Moon does not have the necessary atmosphere. Only myriads of stars without any twinkle in them shone coldly in the sky, filling it with their dull luminosity, and the terrestrial disc still hung suspended there, just as it had the evening before. It looked as if it were fastened to one spot. You see, the Earth does not move about in the lunar firmament as the Moon does in the Earth's, so that when viewed from the Moon, the Earth neither rises nor sets. This characteristic of the lunar landscape is of real service to the people on the Moon, for they can easily determine their bearings on the lunar surface by the position of the Earth in the sky. It is difficult to lose one's way on the Moon, for the Earth can be seen from any part of the lunar surface which is always visible from the Earth. However, as far as the "rear" part of the Moon is concerned the situation is quite different. The landing place was situated relatively near the edge of the lunar disc, which is visible from the Earth, and was in the Sea of Showers, near the famous lonely peak Piton, so that the Earth stood rather low. If our excursionists had been near the lunar pole they would have seen the Earth on the horizon.

And how many stars there were in the firmament! Here on Earth we can see about 3,000 stars with the naked eye, but there on the Moon it felt as though the scales had fallen from the eyes. Incidentally, the position of the familiar, brighter stars had not changed at all. What do a mere 384,000 kilometres which separate the Moon from the Earth mean when compared with the distance to the stars! Such were the thoughts that flashed through the minds of our school children as they waited impatiently for dawn to come.

Suddenly the summits of the high mountains began to shine blindingly against the dark background of the sky, as though lit up by powerful searchlights. Only their summits sparkled. The line of demarcation between

the bright light and the darkness was unusually pronounced. You cannot see a picture like that anywhere on Earth, where the light is diffused in the atmosphere. It was a moment of extraordinary beauty!

There's the Sun! It didn't look at all like the bright-red ball we see during sunrise on Earth, but appeared like a dazzling, fiery gigantic star, preceded by its corona, fountains and streams of light that surrounded it on all sides. The play of colours was such as can never be forgotten! Yet at some distance from the Sun the sky remained the same velvety black, filled with a dull luminosity, and the stars in it continued to shine as they had been shining before.

The oblique rays of the Sun illuminated everything all around, and our school children looked about them. How strange, sullen and lifeless the world about them seemed.

The Sea of Showers, where they were, wasn't a sea at all, any more than the other lunar "seas" are. Not a drop of rain ever fell there. The same can be said of the Swamp of Fogs, near which the ship had landed. It was not a swamp at all, and no fogs of any kind were ever to be witnessed there. These names are merely the result of mistakes made by the first astronomers, beginning with Galileo, who thought the dark regions of the Moon were expanses of water. Actually, the "seas" are tremendous barren stony deserts, while the lighter places on the surface of the Moon were formed of sandy and clayey rock. A layer of dust covers the surface of the Moon, the result of volcanic action and explosions that occurred when meteorites fell. Nowhere was there the slightest area that was perfectly smooth and level. The soil was pitted with craters of various sizes. Some of them had diameters of over 100 kilometres. The whole place all around was cut up by deep fissures and clefts and was covered with piles of rock fragments, all of which made it quite impassable. The soil was chiefly a dark greyish brown, although some of the craters had a light surface similar to pumice. This similarity was enhanced by the minute cavities in many of the surface rocks.

The mountain ranges stood out in sharp relief, with their sharp-edged sides and peaks; there was no sign of any rounded surfaces or smooth passes which are so common on Earth as a result of the action of water and wind.

The absence of an atmosphere makes visibility on the Moon very good; there are no foggy mists in the distance, so typical of the Earth. But

everything on the Moon is so unpleasantly harsh, there are such sharp changes from light to dark that there is absolutely no dusk, which is so pleasing to the eye on Earth. It is impossible to see anything in the shade if there are no illuminated surfaces near by. The youngsters clearly saw the mountains in all their details, even though they were at a distance of 60 kilometres, as they discovered later. True, these mountains did not seem at all high to them, whereas they were really about seven kilometres high, like the highest mountain ranges on Earth. This error is due to the great curvature of the surface of the Moon, whose diameter is about $^1/_4$ that of the Earth's. A person moving away from you on the Moon disappears behind the horizon very rapidly—at a distance of five kilometres he can no longer be seen.

When on Earth our excursionists had heard much about the fact that weight on the Moon is $^1/_6$ that on Earth because of the small mass of the Moon and, therefore, one could leap from a cliff 20 metres high or jump across a ravine of that width without any risk. Some of our young travellers were dying to put this to the test so that later they could proudly tell of their experiences to their friends on Earth. However, their heavy space suits, with all the necessary paraphernalia, made their weight, unfortunately, only slightly less than what it was on Earth, and the massiveness of these suits transformed these agile youngsters into staid "grown-ups" capable of moving about only at a most depressingly slow pace. No chance of performing circus stunts here!

The days of their sojourn on the Moon passed by unnoticed. They were simply packed with interesting things. The children made astronomical observations that are impossible on Earth; they took pictures of the solar corona, organized an artificial "solar eclipse"—all they had to do was to cover the solar disc with a circular piece of cardboard. How proud they were of these rare photographs, which they later showed to the members of their Young Astronomers' Circle!

They recalled the excursions they had made to various "famous" spots on the Moon, which at one time had aroused heated discussions among astronomers. These riddles were solved only after a landing on the Moon had been made. One of the first places they visited was the tremendous crater Plato, which was located not far from their landing place. They wanted to know why the colour of the bottom of this crater became darker when the solar rays fell on it. This crater also attracted their attention

because certain astronomers declared that back in 1948 a bright yellow-brownish luminosity had been seen near it, the trail left by a tremendous meteorite as it fell, one similar to the Tungus meteorite. And now it was interesting to check up on that hypothesis.

They also visited the crater Aristarchus, whose diameter is over 45 kilometres and which is 1.5 kilometres deep. The central peak of this crater is the lightest spot on the lunar surface that can be seen from the Earth. It shines brightly even in the Earth-shine. The children discovered what kind of rock it is that reflects the solar light so well. It was also interesting to learn what those dark radial streaks were that extended from central peak of this crater outwards.

The travellers visited the crater Theophilus, which is a typical crater having a ring of mountains around its circumference and a mountain in the middle, and the Copernicus crater, named after the great Polish astronomer. On their way to Theophilus they flew over the very centre of the lunar disc as seen from the Earth. They enjoyed the view of one of the highest mountain ranges on the Moon, located almost at the South Pole, the Leibnitz Mountains, whose summit is almost nine kilometres above the average level of the lunar surface. There, close to the South Pole, they saw one of the largest craters on the Moon, Clavius, whose diameter is over 200 kilometres. It is also one of the deepest craters, its depth being almost eight kilometres. They visited the Alpine Valley, the only one of its kind on the Moon, which is separated from the Sea of Showers by high mountains. This valley, which is 10 kilometres wide at its widest part and over 120 kilometres long, is smooth, resembling a sort of gigantic gash in the mountain range; its origin has not as yet been satisfactorily explained. The youthful astronauts also visited another lunar "curiosity"—the Straight Wall, which is located in the Sea of Clouds. This ledge, a vertical drop of 600 metres, simply amazed our travellers. What made it so erect and so high? Could it have originated during some terrible "moonquake"?

After flying across the lunar Caucasus the children visited the Sea of Serenity with its mysterious crater Linné, which almost vanished before the very eyes of the astonished astronomers, who had been watching it from the Earth. In the past century this crater had been clearly visible; now it was hardly noticeable. Our young people simply had to find out what had happened to this unusual crater!

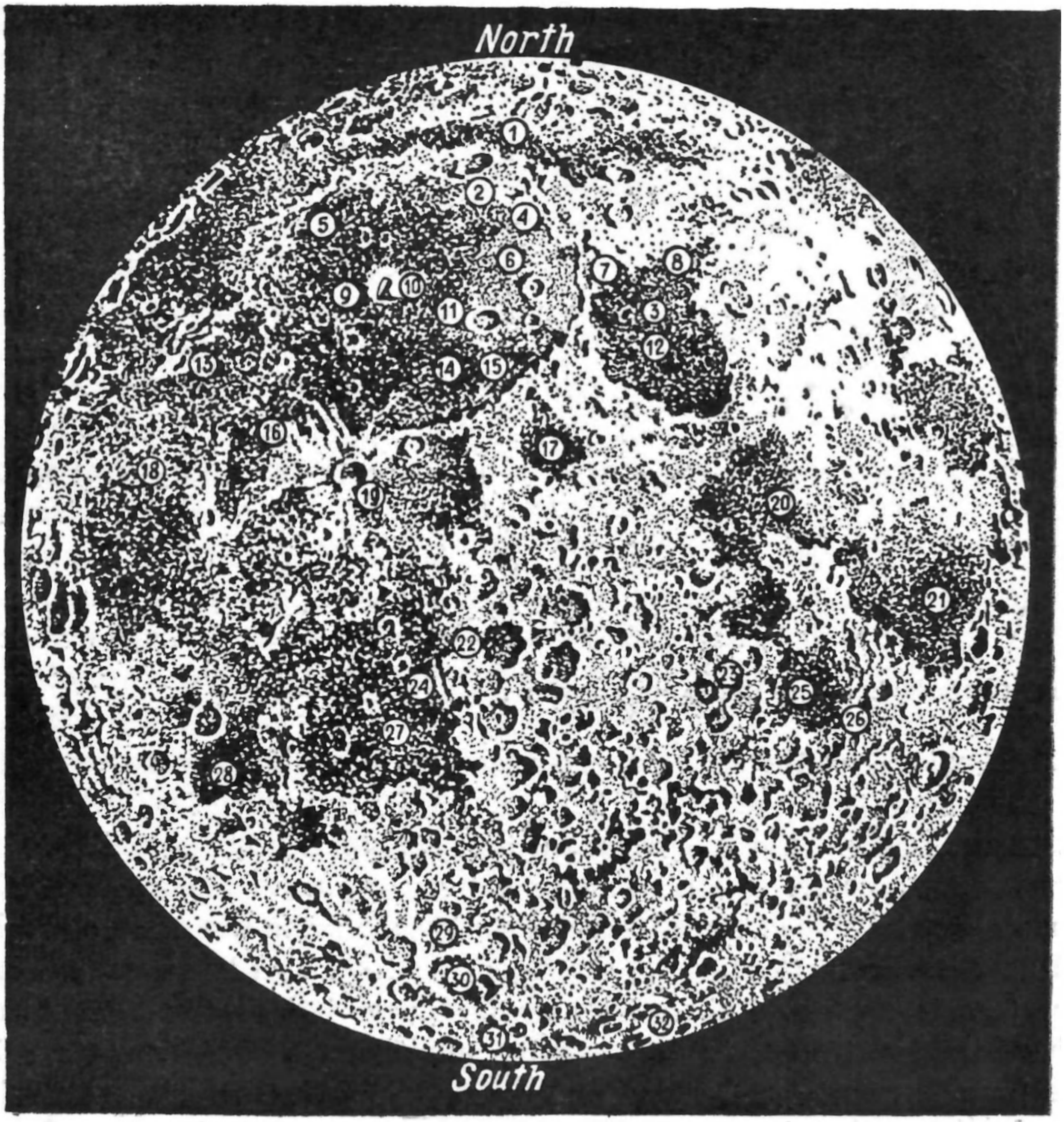
They climbed inside the crater Tycho, which, like many things on the Moon, is so mysterious. It is almost at the southernmost edge of the lunar disc and is the centre of the most powerful system of "rays" on the lunar surface: light coloured streaks that diverge from the crater almost over the entire surface of the lunar disc. Nothing can stop these "rays," neither mountain nor hollow. What are these mysterious "rays"—traces of explosions during volcanic eruptions or did they remain after gigantic meteorites fell? Condensed vapours which filled the clefts that were formed together with the crater? The young astronomers will tell their friends on Earth all about it when they return.

For their travels on the Moon the excursionists had a special excursion rocket ship at their service. While on the ship and after landing they took pictures of everything that seemed especially noteworthy and which they thought might interest their friends on Earth, for they would have to tell them about everything they had seen when they got back.

The attention of these school children was especially attracted to some buildings that had been erected on the Moon in the years following man's first arrival there. They visited the "sublunar" enterprises, where fuels for liquid-fuel rocket engines of space ships were produced. These plants not only fully supplied the ships that landed on the Moon with the fuel they needed, but also the interplanetary stations—the artificial satellites of the Earth and the Moon. Containers of fuel were dispatched to these stations by means of a tremendous electromagnetic catapult.

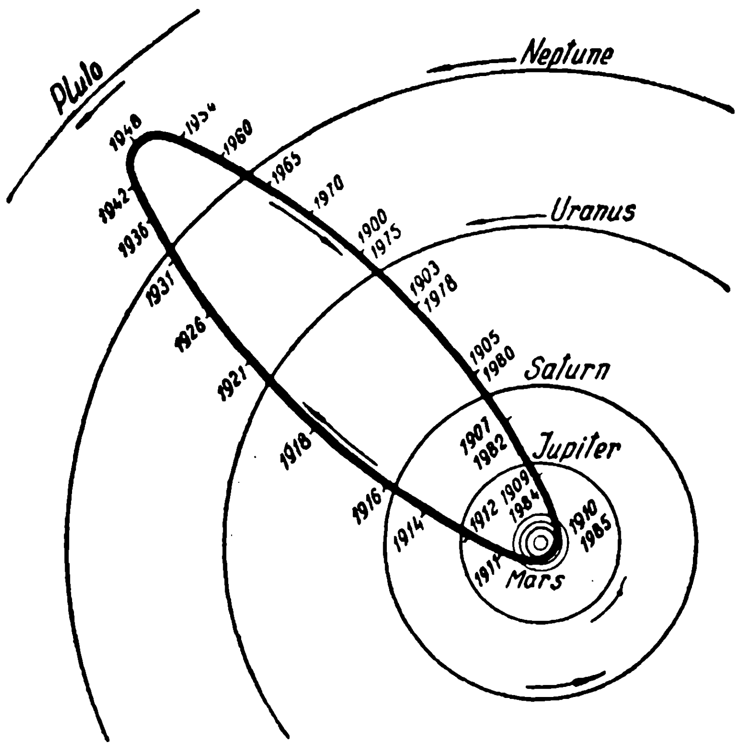
The excursionists also visited the gigantic solar power station which provided the enterprises and dwellings of the lunar colony with electricity and heat. They looked into the central dispatcher's room, from which several atomic power stations, that were at a distance of 150 kilometres from that room, were controlled. They went down into the pits of mines, where many valuable, rare metals and minerals were obtained.

Evenings in the "sublunar" clubrooms the young people watched TV programmes from the Earth. One of these broadcasts was organized especially for them. They saw their relatives and friends. They also had long conversations with veterans who had been living on the Moon for several years and only visited the Earth on their vacations, which they spent at resorts on the Black Sea and at Moscow's suburban sanatoriums. The children probably enjoyed these conversations more than anything else, for they learned much that was both interesting



What the youthful travellers saw on the Moon.

1. Sea of Cold.
2. Crater Plato.
3. Crater Linné.
4. Alps.
5. Bay of Rainbows.
6. Swamp of Fogs.
7. Caucasus.
8. Lake of Dreams.
9. Sea of Showers.
10. Landing place for ship.
11. Crater Archimedes.
12. Sea of Serenity.
13. Crater Aristarchus.
14. Swamp of Putrefaction.
15. Apennines.
16. Carpathians.
17. Sea of Vapours.
18. Ocean of Storms.
19. Crater Copernicus.
20. Sea of Tranquillity.
21. Sea of Abundance.
22. Crater Ptolemy.
23. Crater Theophilus.
24. Straight Wall.
25. Sea of Nectar.
26. Pyrenees.
27 Sea of Clouds.
28. Sea of Humidity.
29. Crater Tycho.
30. Crater Clavius.
31. Crater Newton.
32. Leibnitz Mountains.



Path of Halley's comet in the solar system.

and fascinating about the heroic struggle of these pioneers in the conquest of the Moon.

While on the Moon the young people discovered that there was another surprise in store for them. It was the pilot who told them about it. When flying off from the Moon the ship would fly around its "rear" side, which had become accessible to man only after space ships had succeeded in circumnavigating the Moon. For thousands of years people on Earth had been observing only one and the same surface of the lunar disc, or slightly over half of it, about $^3/_5$ of the total lunar surface. (The children were especially interested to know that the part of the lunar surface which is visible to us on Earth covers an area approximately equal to the surface of the Soviet Union.) This explains why, at all planetariums the world over, one side of the globe representing the Moon was blank. People did not know what this part of the Moon was like. This is due to the fact that the Moon's rotation on its axis under the influence of tidal forces caused by the Earth's force of gravity, gradually slowed down. Once it was faster, but now the Moon makes only one rotation on its axis in the same time that it takes to make one complete revolution around the Earth. The result is that one and the same side of the Moon is always turned towards the Earth. It sways very slightly from its position of equilibrium, which thus enables us to look a little "beyond the Moon." The same tidal forces have transformed the Moon from a globe into a sort of gigantic pear, having formed a protuberance that is almost a kilometre in height and which always faces the Earth.

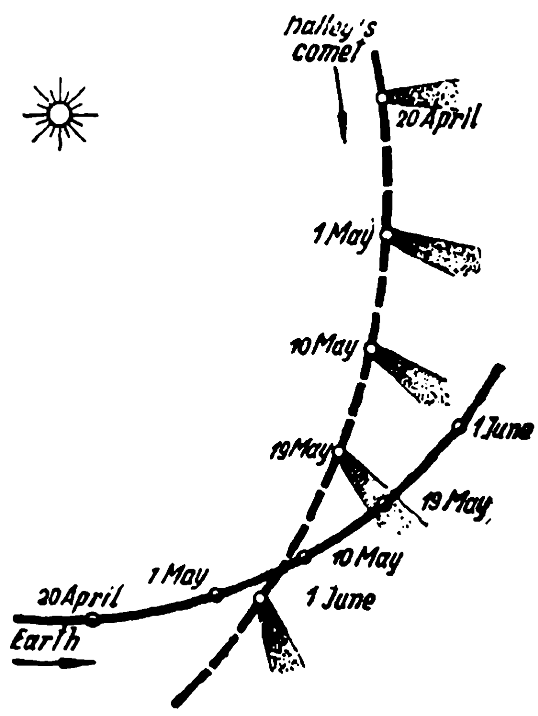
Now the children were able to see the other side of the Moon and photograph it, in order later to tell their friends about it. They were certainly in luck!

But this was not everything. There, against the black sky of the Moon, they saw a rare visitor at the shores of the Earth—a comet, a "shaggy star." It was Halley's comet, which moves around the Sun in an elongated elliptical orbit, returning to it once in three-fourths of a century (to be more exact, once in 76 years). Comets are, perhaps, the most mysterious, even though the most numerous celestial bodies in the solar system (back in the seventeenth century Johannes Kepler said that "there are as many comets in celestial space as there are fish in the ocean"). Most of the comets move around the Sun in orbits which are practically not to be distinguished from a parabola. Such comets return to the Sun only once in several scores of thousands of years, and even hundreds of thousands of years.

According to latest conceptions, these comets come from a colossal "cloud" of icy blocks formed of frozen gases with solid particles in them. These blocks of ice move comparatively slowly around the Sun and at tremendous distances from it. The transverse diameter of this "comet cloud" is 2,000 times greater than the diameter of the solar system. Such is the "barrier" which interstellar ships will have to overcome. Some of these frozen blocks, when they approach the Sun at a closer distance, become comets.

Halley's comet is perhaps the most interesting of all comets that have been observed during their several returns to the Sun. It is very bright, whereas all the other comets of this type are feeble. Its period of revolution is greater than that of any other similar comet. Halley's comet moves in a direction opposite not only to the revolution of the planets around the Sun, but opposite to that of all other known comets. In this relation it is the only exception of its kind.

Halley's comet has been named after an astronomer who was a contemporary of Newton. In 1682 after one of the regular visits of this comet, Halley predicted its return in 75 years. That was the first prediction of this nature. The



On May 19, 1910, the Earth passed through the tail of Halley's comet.

return of Halley's comet can be traced for 2,000 years in ancient manuscripts. The last time it appeared near the Sun was in 1910. On May 19, 1910, it passed between the Sun and the Earth at a distance of 24 million kilometres from the Earth, so that the Earth very likely "pierced" the tail of the comet, which is much larger, about 30 million kilometres.

And now this comet had returned again....*

At last the day for their return to the Earth arrived! It was time to get ready. The Sun was already right above the horizon. The long lunar night with its pitiless frosts was just about to set in. Our travellers, who had quite forgotten about their ship in the excitement of so many lunar affairs, were now unable to recognize it. As when it arrived, the ship stood, nose downward, on its four "legs," but now a tremendous additional tank of fuel had been set up on it. This tank, whose own weight was three tons, contained 36 tons of fuel. Furthermore, two other globe-like tanks with fuel had been set up on the ends of the wings. Each of them weighed only 250 kilogrammes and contained 3.25 tons of fuel. Thus the ship now weighed 68 tons (that would have been its weight on Earth, inasmuch as on the Moon it weighed only a little over 11 tons), of which 58.5 tons comprised the fuel.

The pilot-radio officer whose friendship the children had not forgotten even when they were on the Moon, explained to them why the ship weighed less at the take-off from the Moon than when setting off from the Earth. The escape velocity from the Moon was only $2^{1}/_{3}$ kilometres per second (it is, therefore, not surprising that the Moon lost its atmosphere long, long, ago, as the molecules of gases possessed a still greater velocity and had deserted the Moon for all time). Furthermore, when landing on the Earth, the braking by motor will reduce only half the velocity of the falling ship, while the rest of the speed will be reduced by the resistance of the air when flying in the Earth's atmosphere. It is here that the wings will be of great service. With their aid the ship will be able to glide around the Earth for a long time, during which the remaining, superfluous velocity will be reduced.

"On the whole," the pilot said, "the supply of fuel for the return trip has been so calculated that it should be sufficient to impart to the ship at take-off, when there is no force of gravity or air resistance, a velocity

* Halley's comet should return in 1986.

of 9.2 kilometres per second, which is only 60 per cent of the velocity at the take-off from the Earth. The decrease in the losses in velocity at the take-off from the Moon, as compared with braking when landing on it, and the smaller weight of the additional fuel tanks enable us to decrease the supply of fuel.

After saying a warm good-bye to their lunar friends and having taken along the letters given them for people on Earth our travellers climbed into their cabin, which looked exactly as it had looked before they landed on the Moon. There was the five-storey bedroom and once again the crew was beneath the passengers and the clock was on the floor.

The doors were firmly closed, the motor tested, a green rocket sent off—and the ship, after a short tremble, took off from the Moon.

The thrust of the engine, which, as we know, was equal to 70 tons, was able to impart to the ship weighing 68 tons at the take-off from the Moon an acceleration almost equal to the terrestrial: 10 metres per second for every second. That, of course, is six times the acceleration of the lunar attraction, so that during a vertical ascent the ship's velocity increases by a little over eight metres per second every second of the ascent. At this moment the weight of the passengers is practically equal to their terrestrial weight, the overload being equal to one.

However, as the fuel is consumed, the weight of the ship will decrease and the acceleration increase, since the engine's thrust remains unchanged. By the end of the take-off, when the ship will have a velocity of about three kilometres per second and all the fuel in the auxiliary tanks will have been consumed, the ship will weigh only 32 tons and the overload will be two. Even so, this is less than at the take-off from the Earth, but all were ordered to lie on their berths just the same.

The engine roared. How interesting it all was! Inside the ship, from behind the isolated walls, its roar could be heard, although the sound was muffled. But the dwellers of the lunar colony could hear nothing at all, as far as they were concerned the ship flew silently, as sound is not transmitted in space devoid of air.

The ship had risen only slightly above the surface of the Moon when the commander made a sharp turn sidewards. In order to do this he deflected the axis of the engine slightly away from the axis of the ship. The engine is built in such a way that it can be turned around the same as on heavy long-range rockets. Then the ship began to increase its speed,

flying at a relatively low altitude above the lunar surface. It was more convenient to fly this way. There were no losses in velocity due to lunar attraction and the passengers were better able to see what was going on down below.

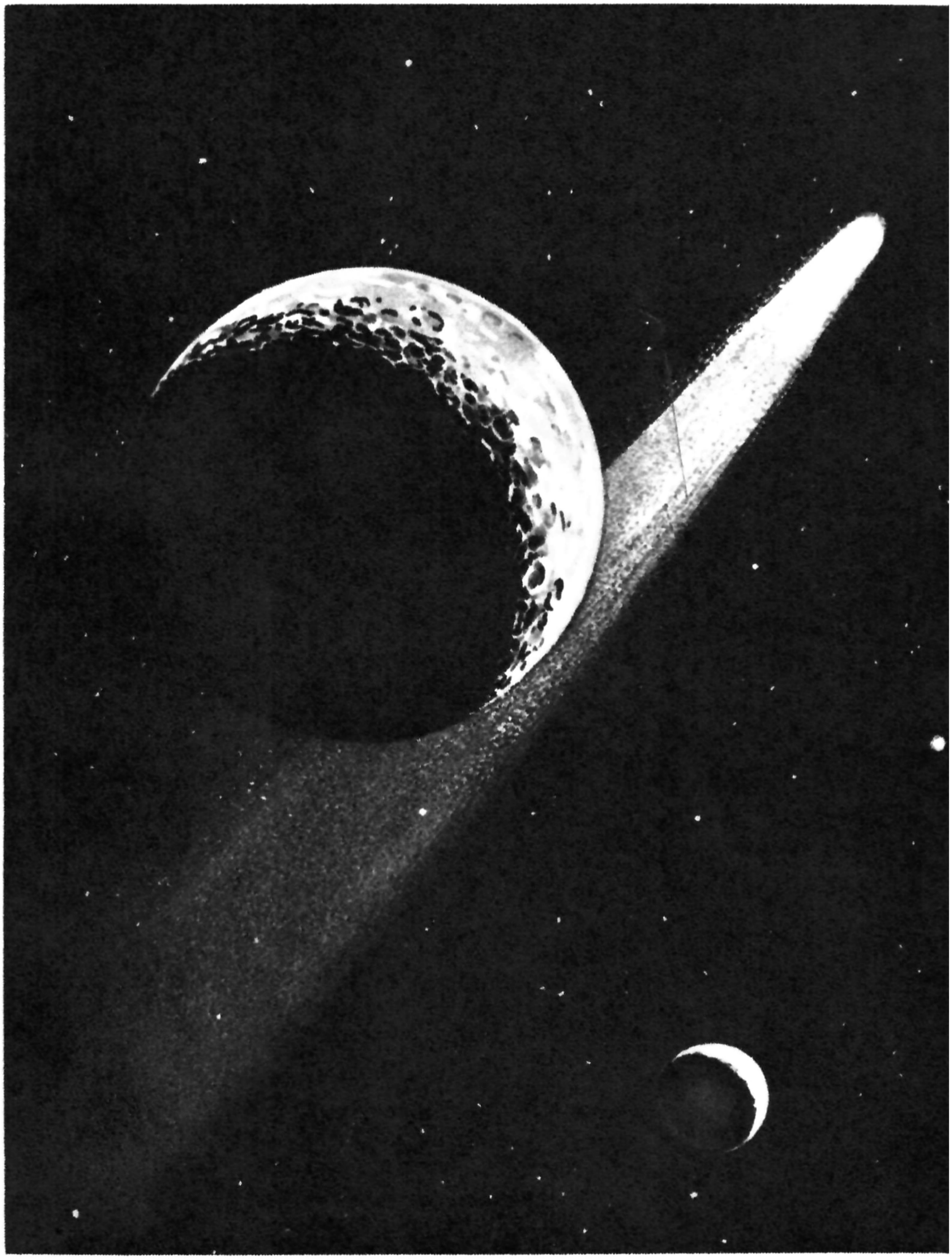
The children were glad to take advantage of the opportunity afforded them. At first they flew over the places already familiar to them. They recognized the hills, seas, craters. But as they kept coming closer to the lunar pole, the Earth almost set behind the horizon. In a moment it would vanish completely from sight, hidden by the Moon. The children got a view of the lunar surface as yet never seen by anyone from the Earth. The landscape they saw was usual for the Moon, only its relief was even more ragged and the surface more uneven.

The lunar surface changes extremely slowly, so that scientists have never been able to establish any authentic changes in it.* Of course, we cannot say that nothing happens on the Moon. Its surface is constantly being subjected to the bombardment of meteorites, to the action of cosmic rays and electronic streams that come rushing out of space. Then, too, the force of attraction towards the Earth affects the Moon. The change in temperature, when day turns to night and the other way round, causes stratification of the rocks on the Moon. But because of the absence of an atmosphere and moisture the processes which cause a change in the character of the lunar surface proceed much more slowly than on Earth.

The most active of these processes are caused by meteoric showers and the change in temperature. When midday changes to midnight the temperature on the surface of the Moon drops more than 250°C., a temperature of from +100° to +120°C. drops to a crackling frost that reaches from —150° to —160°C.** However, this change takes place slowly, gradually, and its effect on the surface of the Moon may be felt only after many millions of years.

* According to individual observations, some small lunar craters, as Linné in the Sea of Serenity, vanished for some time, but later appeared anew. Does this mean they were temporarily beclouded by some smoke resulting from volcanic activity or that they were filled with lava which later sank deep down? Perhaps, but such observations are still not completely authentic.

** The fluctuations in temperature in the areas around the poles is much less than at its lunar equator. In spite of the absence of an atmosphere, the climate in the different parts of the Moon is, after all, different. That is why the site for the lunar base was selected relatively close to the pole.



Halley's comet traverses the Earth's orbit
In front—the Moon

The relatively sharp change in temperature during lunar eclipses is felt much more severely. When the Earth gets in the way of the solar rays that are rushing to the Moon, the temperature of the lunar surface, as measurements show, drops about 150°C., from +70° to —80°C. within one hour. But these lunar eclipses take place only on that side of the Moon that faces the Earth: its opposite side is free of such sharp temperature changes and, therefore, the stratification of lunar rocks on the "rear" side takes place more slowly, and its surface is more uneven.

Absorbed in their observations, the youngsters did not notice when the engine was switched off and the ship began its free flight around the Moon, in order later to head for the Earth. The children could not be torn away from the windows for even a minute, so extraordinarily beautiful was the scene that was being unfolded before them. Two narrow crescents, the closer one, the lunar, and the farther one, which was smaller, the terrestrial, gleamed in the rays of the Sun. Halley's comet glittered blindingly, its fluffy tail spread over the entire half of the velvety-black sky. Venus sparkled above the comet like a precious diamond! Moments never to be forgotten!...

The next two days in the ship's cabin, which felt so cozy now, flashed by quickly. The children kept their eyes fixed on the Earth, which was growing larger all the time. They recognized the familiar outlines of the continents, enjoyed the reflection of the Sun in the ocean, and tried to guess which spot on the Earth's surface was their beloved Moscow.

When getting ready to land on Earth, the commander of the ship decided to turn its nose in that direction. This was desirable when braking the ship by means of the motor, which was set up on the very edge of the ship's nose, and also when gliding in the Earth's atmosphere. The ship should encounter the least possible resistance, otherwise the braking will be too sharp and the ship may become incandescently hot and flare up, in which case it would suffer the fate of countless meteors.

The small fly-wheel in the crew's cabin droned as it was unwound by an electric engine, and the ship slowly began to turn about in the opposite direction. The Earth and the stars floated past them. Only their motion told them that the ship was turning. Now the ship was whirling along, nose forward, ready for its dangerous encounter with the Earth's atmosphere.

The tremendous fuel tank, now no longer needed, had been thrown overboard and burned up in the atmosphere, which it had penetrated at a tremendous cosmic velocity.

The pointer that showed the number of kilometres remaining to the Earth's surface kept moving rapidly. Only 2,000 kilometres remained, 1,500. A robot artificial satellite which kept moving constantly around the Earth in its two-hour orbit at an altitude of 1,669 kilometres, that is, making one complete circuit of the Earth in two hours, flashed by them. Judging from the shape of this satellite, it was used as a robot station for relaying television broadcasts.

The velocity of the ship exceeded 10 kilometres a second, over 36,000 kilometres an hour. If the landing was to be a safe one, the velocity of the ship had to be reduced by braking with the engine.

The commander switched on the engine and again, for a little over three minutes, the inertia overload pressed the bodies of the travellers to the spring nets of their berths. The ship's velocity dropped to five kilometres a second. In less than 40 seconds after the ship had begun to brake, the tanks on the wings, which had now become unnecessary, were jettisoned.

The ship began to glide down from its altitude of several hundred kilometres. It will make more than one complete circuit "around the globule" before its velocity is reduced to the flight velocity of jet planes; then it will become still less. Of course, the ship will fly in the direction of the Sun, towards the east, that is, in the direction in which the Earth rotates on its axis; in this case the Earth's rotation will help to reduce the relative velocity of the ship more quickly. There is Moscow on the horizon! It is a bit to one side. The ship flies to the very same cosmoport from which it had taken off on its distant journey so very recently. The aerodrome of the cosmoport is quite close already. The commander moved the control stick away from himself, thus directing the ship's nose downward towards the Earth. The operating motor retarded what was left of the velocity, and the ship smoothly landed on its "chassis-legs," which had been let out beforehand.

Welcoming shouts, joyful exclamations, the waving of hands, and hurrying and scurrying here and there.... Earth!

* * *

"A dream, mere fantasy!" you will say. True, a dream. And fantasy, of course. But how many such bold dreams have been converted to the most real of realities by the creative labour of man, by the achievements of science!

We are firmly convinced that the time will come—and it is not far off—when even this boldest of all the boldest dreams of mankind will come true.

We firmly believe that as the years pass, perhaps decades, manned space ships will set off on flights to distant worlds, worlds that are so alluring!

Permit me, dear reader, to wish you the opportunity of taking part in such a flight.